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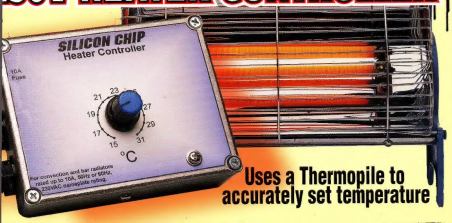

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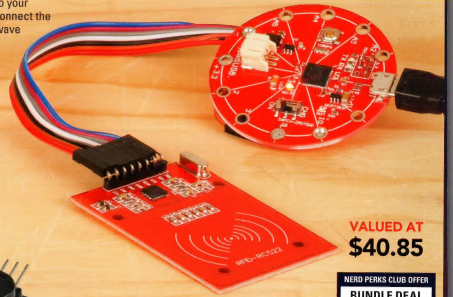

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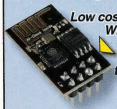

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Subscription rates: $105.00 per year in Australia. For overseas rates, see our website or the subscriptions page in this issue.

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Printing and Distribution:
bluestar
Derby Street, Silverwater, NSW 2148.

ISSN 1030-2662
Recommended & maximum price only.

Editorial Viewpoint

New blood at SILICON CHIP

This month I am delighted to welcome two new members to the SILICON CHIP editorial team, Tim Blythman and Duraid Madina. Tim has hit the ground running as he is responsible for two projects in this issue.

Duraid is a part-time technical contributor who is already busy beavering away on a couple of state-of-the-art projects which should come to fruition later this year. We are really looking forward to presenting them for your enjoyment.

Both these new team members should greatly expand our expertise and "project generating" capacity and we look forward to a whole range of interesting new possibilities.

Just one of these new possibilities involves more projects based on the ESP8266 (and related) chips. That's because these offer an ease-of-use that's similar to the Arduino Uno but with inbuilt WiFi, a lot more flash memory and a much faster CPU.

In effect, you get an Arduino-compatible processor with WiFi but in a smaller, more powerful package – all for a similar or, in some cases, lower price.

The fact that the same chip is available in a range of form factors, from the Uno-compatible D1 R2, to the smaller but equally capable D1 Mini, and even the tiny ESP-01, means they are especially flexible.

But it's the inbuilt WiFi, with easy-to-use libraries, that's really the "killer" feature. It makes it so easy and cheap to design projects that fetch data from or upload data to internet servers and that opens up a huge range of possibilities. It can also allow us to control our designs from a smartphone.

The WiFi Water Tank Level Meter presented in the February issue has turned out to be very popular. The prototype is in use on my rainwater tank at home. In this current prolonged dry period in Sydney it has been an important reference for me to determine how much to water the garden. I can easily check the water level from the office using my phone.

Still on these WiFi modules, one of the great things about using the Arduino IDE to program many of the ESP8266 boards is that all you need to re-program it is a PC (Windows, Linux or macOS) and a USB cable.

And given that many of our designs can be expanded for uses other than those they were intended for, I hope that readers take advantage of this capability to extend our concepts. After all, we make the source code available and there's nothing stopping you from modifying the code to add new features.

If you do manage to enhance or adapt one of our designs to another application, please write in and let us know. It could even be the subject of a new project article or an item in SILICON CHIP. Consider that we do pay for article contributions.

If you don't have any programming experience, Arduino is a good place to start. While it may seem more daunting than learning a language like BASIC, the C family of languages it is based on are probably the most widely-used programming language in existence; your time learning it will be well spent. And there are a huge number of pre-written libraries available for a range of tasks, so you don't have to waste your time "re-inventing the wheel".

Finally, I hope that our Australian and New Zealand readers will enjoy combing through the latest Jaycar catalog included with this issue. We always enjoy such catalogs included in the magazine, since even in these days of internet searching, nothing can match the convenience of a printed catalog that you can refer to at any time. You never know when you will come across a nifty little gadget or component which will be of great use.

Nicholas Vinen

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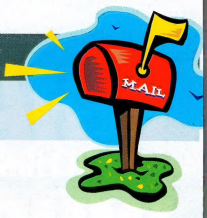

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More information on brushless alternators

I believe that your comments on brushless alternators on page 62 of the February 2018 issue, in Serviceman's log, are valid. Many aircraft use this type to generate 3-phase 400Hz 115VAC power.

However, in the case of the GMC units, I think you will find that these use a different technique. They are called "capacitor-excited brushless alternators".

The rotor has one or two windings, terminated with a diode. There are two stationary windings in quadrature. One of these is the output winding, the other, known as the auxiliary winding, is terminated with a capacitor.

This capacitor is crucial for the unit to self-excite. Increasing the capacitance should increase the output voltage. The self-excitation relies on residual magnetism and sometimes it is necessary to "flash" the stationary fields to restore this.

These generators are sometimes known as "harmonically excited" and as such, are sensitive to the shaft RPM. I have heard stories about over-voltages occurring during startup with a load connected. The output waveform is rarely sinusoidal.

How do they work? I'm not sure but I believe smoke and mirrors must be involved somewhere! There is information available on the 'net. Note that these generators are not what is meant by an "induction generator", which is an induction motor driven above synchronous speed.

US patent 4786853 details a modification of this type of circuit to adjust the output voltage but also gives some explanation of how such a generator works. See **https://patents.google.com/patent/US4786853**

On another topic, an article on aircraft power systems may be of interest to your readers. The standard changed from 28V DC in the 1930s to 115VAC 400Hz 3-phase in the 1960s.

These systems were mainly "copper and iron". Nowadays there are all sorts of electronic systems. One of the challenges is that the prime mover (typically a gas turbine) does not run at a constant RPM but varies over a roughly 2:1 range from ground idle to maximum thrust.

The solutions include variable speed alternators with AC/DC converters, followed by DC/AC inverters, sometimes using the HV DC from the converter directly.

Some loads are able to use the 350 to 800Hz output directly. There's some information on aircraft electrical systems here: **siliconchip.com.au/link/aaj9**

Thank you for your most informative magazine.

Norm Smith,
Shoalhaven, NSW.

Brushless alternator used in generator is quite simple

In the February 2018 issue of SILICON CHIP, in the Serviceman's Log, B. P., of Dundathu, Qld, describes the phoenix-like spells that he performed on two GMC small generators which he identified as having no brushes. At the end of his description, the Editor copied from Wikipedia a description of a brushless alternator design.

But there is more than one type of brushless design and the GMC generators, which are the subject of the story, are not according to the Wikipedia description.

The design described by Wikipedia has many auxiliary supporting components and in a modern rendition there are a large number of electronic components in the associated voltage regulator (AVR) and that type of brushless alternator, while eliminating the brushes, is actually quite complicated.

The GMC generators, like most small portable generators, could not have fewer electronic components, namely, just one capacitor and one diode.

To explain how they work, it is helpful to digress and contemplate a half-wave rectifier power supply using a single diode and a transformer. The transformer has to be de-rated because the DC flowing in the secondary winding magnetises the laminations, causing them to saturate during part of the cycle.

In a similar fashion, the rotating part of the alternator has laminations and a

Water Level Sensor supply voltage not critical

I look forward to my copy of SILICON CHIP in my letterbox every month, thank you. The Water Level Meter in the February 2018 issue is a great project.

However, I would like to point out that the LM358 (IC1) is not required. Simply replace the shunt with a 150Ω resistor and you will get the 3V signal required.

Devices which operate using the 4-to-20mA protocol are very robust. They are designed to operate with long lengths of cable between the sensor and measuring device. So they are very tolerant of voltage variation.

Therefore, the sensor does not need to be powered with exactly 24V. Not only will it work fine at 23.8V, it will also work fine at say 16V.

I also note that under Power Supply Circuitry section, MOD5 is identified as MOD4.

Steve Dyer,
Carrara, Qld.

Comment: thanks for pointing this out. The specifications supplied with the Water Level Sensor simply gave a nominal supply voltage of 24V with no range, so we were not comfortable allowing it to vary so much. We have since seen websites claiming it will work over a range of 12-36V which supports your statement.

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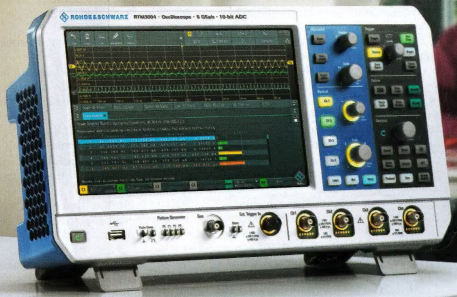

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single winding with a diode connected directly across the two ends of the winding. As the rotor rotates and the magnetic flux in the rotor alternates, this causes current to pass in one direction through the rotor coil which in turn causes the laminations in the rotor to become magnetised.

In many ways, the rotor now behaves like a permanent magnet rotor. But when the generator first starts, there is no current flowing in the stator windings and so to get the ball rolling, a winding in the stator has a capacitor permanently across it. So with the small residual magnetism in the rotor, current builds up in both that stator winding and in the rotor until the rotor saturates.

Because the current flowing in the rotor through the capacitor is out of phase with the voltage in the capacitor, no power is wasted in that part of the circuit. A resistive load would also have worked but that would have been wasteful. That was the capacitor that the author had to replace.

Now, with a strong magnetic field rotating with the rotor, another winding in the stator will also have voltage induced and it is that other winding that is connected to the generator's output terminals.

By cunning design, which involves the capacitor winding in the stator being out of phase with the output winding and by tweaking other design features, better voltage regulation can be achieved than with a simple permanent magnetic rotor.

However, the output waveform is always horrible and the distorted waveshape is load dependent. But for many purposes this does not matter and as the design is cheap to manufacture it is also a popular design. In my experience, the design is associated with small portable generators.

Dr Kenneth E. Moxham,
Urrbrae, SA.

Some servomotors require significant bypassing

Thank you for another interesting edition of SILICON CHIP. I only have one comment about the February 2018 edition and that concerns the use of the Woodlawn open-cut mine as a tip. What a waste!

There is an excellent site for a pumped storage system for the electricity grid and instead, it is being used as a depository for rubbish.

Anyway, I have just been through a fault-finding exercise and it may be of interest to some readers. I decided to make another little tricycle-type robot after reading about the Squee robot on David Buckley's website at: **siliconchip.com.au/link/aaja**

Edmund Berkeley demonstrated that complex behaviour could be produced using only some simple boolean logic and I thought that it might be interesting to replicate it.

However, instead of making an exact replica, I would implement the logic using a microcontroller and change the steering drive to a radio-control type servomotor.

I purchased a standard servo from one of the retailers and tested it. But instead of a smooth precise action like my other servos, it behaved very erratically.

I checked the web to see if there were problems with these servos and there appeared to be none. I then wondered what I had done wrong. So, I decided to buy a second one which behaved in exactly the same way.

I dismantled one of them and saw that there was a microcontroller and a simple Mosfet H-bridge to drive the motor. The supply was only bypassed with a 22µF tantalum capacitor. That did not impress me and I suspected that the problem may be caused by the high current when the motor switches on.

To test the idea, I placed a 100µF low-ESR electrolytic capacitor across the supply and turned the servo on. There was a substantial improvement. I then tried a 470µF low-ESR electrolytic and the servo responded with considerably less jitter but still some erratic behaviour. I then looked at limiting the motor turn-on current.

Normally, I limit motor turn-on current with a constant-current circuit. But that was impossible in this case. Instead, I decided to insert a small resistor in series with the motor.

The reasoning is that, at turn-on, the resistor would reduce the surge current substantially. Whereas, when the motor was running, the resistor would only cause a small voltage drop.

I inserted a 3.3Ω resistor and retested the servo. What a difference! The servo responded smoothly and precisely, just like my Futaba and Hitec servos.

Later, I thought about the fact that there were no complaints on the web. It occurred to me that normally the servos would be powered by a battery which could supply large currents. Consequently, there is little drop in the supply voltage and the microcontroller is not affected by the motor turn-on current surge.

In my case, the power had been supplied from a 7805 regulator with limited current capability which was unable to provide the surge current. It would have been so easy to believe that the servo was at fault, particularly when the Futaba and Hitec servos worked correctly in the same situation.

Anyone controlling a servo from a Micromite, Arduino, Raspberry Pi, PICAXE etc should be aware of the surge demand and take appropriate steps to address it.

George Ramsay,
Holland Park, Qld.

Comment: this probably could have been avoided if the designers had included an RC filter and/or regulator in the microcontroller power supply. You will notice that some of our designs include such features.

Using an Induction Motor at low speed with decent torque

The Lath-E-Boy project in the January 2018 issue was quite interesting and I'd like to offer some ideas for potential improvement.

Mention was made in the article of operating down to about 5Hz but at that frequency, I have found the torque capacity of any induction motor to be very low.

This is quite the opposite of what we require for machining, as for the same surface speed on a larger diameter cut, when the RPM needs to be reduced, the torque requirements are increased. Belt reduction (or any gearing method, really) provides this extra torque at low speeds.

Using the IMSC at low speeds, the spindle speed will, therefore, be unstable with cutting loads and there is a risk of the motor stalling.

Only "Flux-Vector" or "Field-Oriented" drives are able to produce 150% of rated torque at zero speed on 3-phase motors.

So, I decided to do some bench tests using the one horsepower, 4-pole permanent split capacitor (PSC) motor on my pedestal drill. Admittedly, the characteristics of a PSC motor will differ from those of a capacitor start unit but I still think some lessons can be learned.

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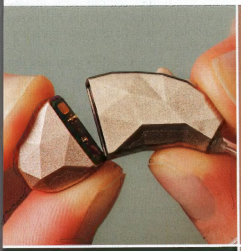

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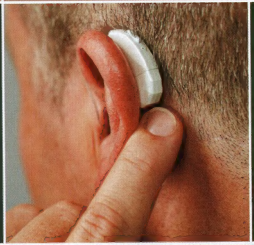

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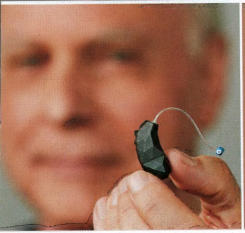

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I separated the start winding from its run capacitor and arranged things so I could run the motor from my IMSC with either a) the start winding disconnected, b) connected via the capacitor (normal), or c) connected to the IMSC's extra phase (as per the article). I monitored the power use from the mains and found the following:

- Switching on at a low speed setting (maybe 10%), with the run capacitor in-circuit, the motor moved but was unable to start (with belt friction only).
- At the same speed but using the extra phase drive, the motor would start but only just keep going once the phase was disconnected.
- With the capacitor in place, once running, the drive ran a little better but it was still fairly easy to stall by hand. The separate phase drive provided noticeably better torque but still not that much.
- At an intermediate speed, the power consumption barely changed with the "start" winding disconnected or connected via the capacitor. It drew the most power at low and high speeds – the capacitor seemed to "fill out" the torque curve a little.
- It was still possible to stall the motor by hand when using the capacitor, but not with the phase connected.
- At full speed the start winding current (measured using a clamp meter) was much the same with the extra winding driven via the capacitor or directly from the extra phase. A surprising result.
- However, the motor power consumption increased by about 50% with the separate phase drive, so the motor would be dissipating more heat.
- At an intermediate speed, the start winding could be left connected without high dissipation (but, I only had the belt load).

As a result, I feel the following should provide a useful increase in lathe torque:

- Leave the start winding connected to the extra phase for low-speed operation – when the drive voltages are reduced anyway. Use feedback to maintain speed.
- At low-to-intermediate speed, use relay contacts to change over the start winding from the extra phase to a normal run capacitor – a lower-value unit than the start capacitor may prove optimal.
- At intermediate-to-high speeds, fully disconnect the start winding.

Obviously, a larger motor will also provide a torque improvement.

I had hoped (for the PSC motor) that I could leave the capacitor in circuit and only temporarily connect the extra phase to the start-winding/capacitor junction but this proved not possible. The IMSC kept tripping out and indicating a fault.

PSC motors do not have a high starting torque, so are best only used for fan and centrifugal pump loads (ie, low torque requirements at low speed). It works OK on the drill press but does tend to "bog down" with bigger drill bits.

I also have a question regarding the purpose of the "Output Frequency Sense" circuitry in the Lath-E-Boy. Given that the IMSC has a 1:1 relationship between V_{IN} and the drive frequency, is any of this needed? Is it there to correct for non-linearities in the PWM outputs of OPTO2 or the IMSC input?

Either way, this only controls the output frequency, not the spindle speed; increased slip in the induction motor slip will result in a lower spindle speed and this depends on the motor loading.

A more accurate method to "close the loop" would be to measure the actual spindle speed, using say, a magnetic pickup and feed this back through the "READ RPM" circuit.

Ian Thompson,
Duncraig, WA.

Comment: thanks for this information. As you suggested, we expect the feedback as presented in the project article would primarily act to cancel out non-linearities in the optocoupler.

Valves with similar functions can have different pinouts

The Vintage Radio article on the Philips 148C in the March 2018 issue was, as usual, a great read. When I came to the description of the apparently miswired 3V4 output valve socket on page 95. I remembered from my early days in the 60s, messing around with battery valve sets and construction projects, that there were two "3"-series battery pentode output valves, the 3V4 being one of them.

But it was so long ago that I had to consult my trusty Miniwatt valve data manual to find the other.

It was the 3S4 and from what I can determine from the description in the Vintage Radio article, the wiring

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12SB3AC	12	34	197	131	159	170	10.5	M5 Bolt	Dual Purpose
12SB3BC	12	35	197	131	159	168	10.7	M5 Bolt	Cyclic
12SB4DCL	12	43	198	166	171	171	13.1	M5 Bolt	Dual Purpose
12SB5BC	12	50	195	166	171	171	14.3	M5 Bolt	Cyclic
12SB5DCL	12	55	225	135	207	214	17.0	M5 Bolt	Dual Purpose
12SB6DCL	12	60	350	166	174	174	21.6	M8 Bolt & Nut	Dual Purpose
12SB8DCL-FR	12	90	260	170	202	205	24.0	M8 Bolt	Dual Purpose
12SB110CLS-FR	12	110	306	168	208	214	30.5	M8 Bolt	Dual Purpose
12SB120CL-FR	12	120	338	170	212	215	32.5	M8 Bolt	Dual Purpose
12SB140CL-FR	12	140	302	170	270	276	40.9	M8 Bolt	Dual Purpose
12SB180CL-FR	12	180	302	170	270	276	46.0	M8 Bolt	Dual Purpose
12SB220CL-FR	12	220	522	238	219	222	66.5	M8 Bolt	Dual Purpose
GEL Type									
12GB7C	12	7	151	65	94	102	2.7	F1 (Faston 187)	Cyclic
12GB12C	12	12	151	98	93	98	4.0	F2 (Faston 250)	Cyclic
12GB17C	12	17	181	76	167	167	6.3	M5 Bolt & Nut	Cyclic
12GB22C	12	24	166	175	125	125	8.5	M5 Bolt & Nut	Cyclic
12GB28C	12	28	197	131	159	168	12.1	M5 Bolt	Cyclic
12GB35C	12	35	195	166	171	171	14.3	M5 Bolt	Cyclic
12GB55C	12	55	225	135	207	214	17.0	M5 Bolt	Cyclic
12GB65C	12	65	350	166	174	174	23.8	M8 Bolt & Nut	Cyclic
12GB75C	12	75	260	170	202	205	24.0	M8 Bolt	Cyclic
12GB100C	12	100	306	179	212	215	34.0	M8 Bolt	Cyclic
12GB150C-FR	12	162	559	110	266	266	50.0	M8 Bolt	Cyclic

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would appear to suit the 3S4 and not the 3V4. They are similar valves but with different internal connections. The pinouts are as follows:

Pin	3V4	3S4
1	F-	F-
2	A	A
3	G2	G1
4	NC	G2
5	FT-G3	FT-G3
6	G1	A
7	F+	F+

Ian Sorensen,
Toodyay, WA.

Criticism of Lathe controller design

I am disappointed in the "Lathe-E-Boy" machine tool motor speed controller. I think your designer has not fully grasped all the essential requirements of a machine tool VSD (variable speed drive) that a machinist desires in order to exploit the full utility of their machine. There are two glaring omissions in the design.

Firstly, the controller needs to automatically ramp the spindle speed up and down when doing long facing cuts; typical of faceplate turning work.

This is to maintain the optimal surface speed when the cross-slide is auto-traversed toward the centre. The spindle-speed must increase geometrically in concordance with the reduction in diameter and vice versa.

This is achieved by the installation of slide-scales in typical DRO (digital read-out) installations. These retrofits are now de rigueur and are cheap and readily available (mostly from Asia, eg, via eBay or Alibaba).

Just about every other article in the engineering hobby magazines describes an amateur machinist retro-fit to their lathe or mill.

Once installed, it would be a simple matter to implement this feature via a circuit/software interface.

Secondly, electric braking is required. I think your designer has not grasped the importance of this feature. It's not just for safety reasons (although that is most important) but rather, it has general utility as an aid to certain machining operations. For example, machining up to a shoulder, such as when threading into a corner.

This is normally implemented by means of an adjustable stop-rod closing a microswitch connected to the controller. With this method, optimal spindle-speeds can be safely used without fear of mis-timing the stop-point (ouch!).

It's probably also worth mentioning that it is a great pity that the Induction Motor Speed Controller could not be up-rated to handle three horsepower (2.2kW) motors.

These generally represent the typical upper-limit of what would be found in a great many amateur workshops. Look at the used and new machine-tool listings and you'll see what I mean. For example, the Harrison M300 lathe commonly uses a 3hp motor.

Andre Rousseau,
Auckland South, NZ.

Peter Bennett, the designer, replies: the design intent was to minimise belt changes on a very simple lathe that hobbyists may have in their workshop, not try to convert the lathe into a more modern design or one suited to commercial production work.

With enough time, effort and expense, we could turn it into a full CNC machine, but that is beyond the original scope of the project.

Regarding the power rating of the Speed Controller, we arrived at a 1.5kW rating as this is about as high as you can easily go with the power source being a 10A GPO.

While 10A mains can nominally provide up to 2300W, the fact that the mains is rectified to provide pulsating DC which is then switched to the motor drive causes the input current to be higher than you might expect for a given output power.

A hare-brained scheme

I saw your November issue featuring the Dipole Loudspeaker System (siliconchip.com.au/Article/10865) and this sparked some interest from me. My friend and I have been working on a project centred around exciter speakers but which has nothing to do with audio sound reproduction.

While working with exciters, as a matter of curiosity I mounted various types of exciters under my dining room table, side boards, work benches coffee table etc and have played many a song through this system.

My friend even mounted two on the bottom of a acoustic guitar and he clowns around playing guitar songs and hamming it up as if he is the

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actual guitar player. The strings even move in tune with the sound.

To me (through my half deaf ears) the sound reproduction is surprisingly good. So the favour I am asking of you is to write an investigative article exploring just how good the sound really is with this arrangement. I think it would make an interesting article and perhaps answer my question on just how good that sound really is.

My favourite exciter is the Dayton HDN-8 40W 8Ω unit.

Bob Young,
Mt Waverly, Vic.

Leo Simpson responds: Surely, you are joking Bob.

As useful as these devices are, there is no way that an exciter bolted to a wall, ceiling or any other panel can give full-range sound.

While the device has a stated frequency range of 40Hz to 15kHz, no timber, gyprock or any other panel material is likely to produce frequencies above 3 or 4kHz, at best. Another hurdle is that the device has a resonant frequency of 695Hz. How would you get a flat response below that point?

I cannot see much point in doing exhaustive tests when it would be quite simple to do a straightforward comparison test of a full range hifi loudspeaker system with an exciter bolted to a panel; any panel, box, wardrobe, coffee table or coffin.

Coax quality matters when installing a TV antenna

First of all, congratulations on your 30-year milestone. I have every issue going back almost that far and can see how the quality of the magazine has improved by leaps and bounds. I am always impressed and learn many things each month from the magazine.

I just wanted to add a few comments regarding the VHF antenna project in the February 2018 issue. I realise we are only talking VHF here but for best noise immunity, I would use nothing less than RG6 (quad shield) coax. The best fittings to use for terminating the coax are the F-type rather than the saddle type.

It is also worth adding a masthead amplifier to improve the signal-to-noise ratio at the start of the run, if long runs are likely or if the signal is to be split for extra outlets. The crimping tool, F connectors and RG6 coax are all available at Bunnings now, as well as Jaycar, Altronics etc.

Geoff Coppa,
Alstonville, NSW.

Differences between Australian and Chinese mains plugs

Thanks for printing my switchmode power supply repair story, in the Serviceman's Log section of the February issue. I think it was a pity you didn't print the circuit diagram I supplied, which showed how the rectifier bridge could be configured as a voltage doubler for 110VAC mains and full-wave rectifier for 230VAC mains. I thought that was a smart way to use a link to achieve this.

Having said that, nowadays, most switchmode power supplies will work over a range of something like 100-250VAC at 50Hz or 60Hz, so you can just plug them in, anywhere in the world and they will work without any changes.

That means you can often import mains-powered equipment from overseas and it will work in Australia.

But one thing that's often missing from such imported equipment, but is present on all modern Australian gear, is the insulation at the base of the Active and Neutral pins. It seems that in some places in China, they use a plug like ours but they don't have the pin insulation.

Roderick Wall,
Mount Eliza, Vic.

Comment: the standard Chinese 3-pin mains plug is indeed very similar to ours but there are some key differences, besides the lack of insulation at the base of the pins that you mentioned.

These are that the pins are not quite as thick as an Australian plug and the plastic insulation is usually a lot thinner (making for a more compact plug).

Note that in China, a different plug and socket is used for two-pin appliances and it appears very similar to that used in the USA (ie, two parallel rectangular pins).

The pin thickness can be an issue because it means that the plug may not be very secure in an Australian socket. And while you can plug Australian gear into a Chinese GPO, it's usually a very tight fit!

The smaller plastic housing is arguably less safe as it's easier to break, so it's best to chop them off and wire in a proper Australian plug. You should also be aware that such equipment may not be built to the same safety standards as gear sold in Australia.

Portable battery mains power supply wanted

The other day I was outside using an electrical appliance connected by an extension cord. These days the trend has been to battery-powered appliances with convenience and portability being the main drivers.

The thought came to me: for those with mains-powered appliances, why doesn't someone design a portable inverter that fits into the likes of a small backpack or "bum bag" which the 230VAC appliance can be plugged into? I was thinking that lithium-ion battery packs that are used to power battery tools could be the source of power, either stripped down for the batteries or connected with suitable adaptors.

I am not sure on the legalities/safety issues, although we can dangle 230VAC extension cords around the garden with "no worries". I assume they could be designed with appropriate safety measures in mind.

I would be interested in your thoughts.

Peter Ward,
via email.

Response: while theoretically possible, we don't think this would be terribly practical. Safety issues aside (I certainly don't like the idea of having a mains inverter strapped to my body!) even a large battery pack would struggle to provide more than a few minutes of runtime for an appliance which may draw well over 1000W when operating. It would also be quite cumbersome and heavy.

Theremin featured in Australian movie

The playing of the Theremin is a major part of last year's movie, "3 Summers". It will be available for home viewing in March this year. To see a preview, which includes a Theremin being played, see www.transmissionfilms.com.au/films/three-summers

A. Hughes,
Hamersley, WA. SC

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Infrared Sensing Heater Controller

With summer rapidly becoming a distant memory, you will no doubt be dragging out the heaters to stay warm. Our new Heater Controller allows you to select exactly how much warmth you want from the heater and it can even be fitted with a thermopile sensor for precise temperature control.

Most electric radiators are pretty crude devices: you switch 'em on and they get hot.

But in small rooms, they will quickly get *too* hot and then you will want to switch them off or possibly down a level or two, if they have such a switch.

Most heaters pump out too much heat for a small room, even when they are on the lowest setting. You really need a heat controller. Our new Heater Controller is exactly what you want. Think of it as a "dimmer for radiators". But it is a lot more than that.

We should note that some heaters, typically oil-filled units, do have a thermostat where the heater switches off when the air temperature reaches a set value and then it switches back on when the heater cools down.

The thermostat is usually mechanical and often makes a clicking noise whenever the switching occurs and it may also cause a neon or LED to flash on and off at the same time.

That intermittent noise and light may be be disturbing if the heater is used in a bedroom while you are trying to get to sleep.

It can also result in a noticeable heating/cooling cycle if you are close to the radiator.

Our new Heater Controller has no mechanical switching to cause noises and it incorporates a thermopile infrared sensor so it can maintain a set temperature in a room.

Alternatively, it can be built without the optional infrared sensor so you can use it to simply select the amount of heating that you desire.

by John Clarke

We should point out that the Heater Controller is *not* suitable for fan heaters. At the lower settings the fan will not run and that could cause the unit to over-heat and fail.

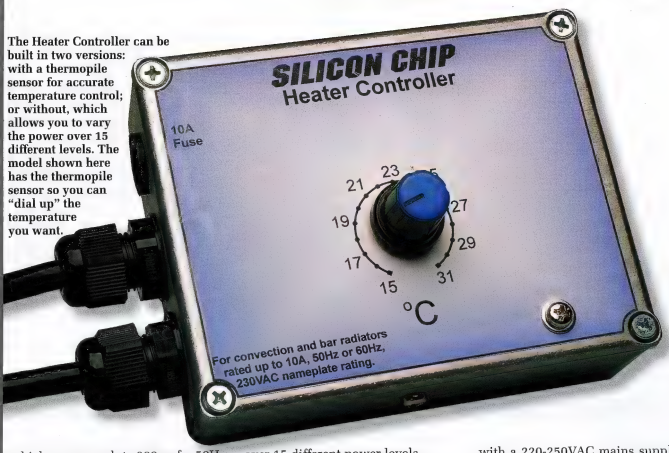
How it works

Our Heater Controller works by applying an integral (ie, whole) number of full mains voltage cycles to the heater.

At lower power settings, fewer cycles are applied and for higher power, a greater number are applied. We have included a number of scope grabs to illustrate this switching operation.

For example, at low power, it may only apply one cycle of 50Hz 230VAC out of every 15. At full power, the mains voltage is on constantly (as if the controller was not present).

It uses a 15-cycle control period,



The Heater Controller can be built in two versions: with a thermopile sensor for accurate temperature control; or without, which allows you to vary the power over 15 different levels. The model shown here has the thermopile sensor so you can "dial up" the temperature you want.

which corresponds to 300ms for 50Hz mains (like in Australia, New Zealand and the UK) or 250ms for 60Hz.

At half power, there are seven or eight cycles of mains voltage applied to the heater out of 15 incoming cycles.

The switching action will not be noticeable with heaters with wound resistance elements but it will be visible with radiator elements in silica glass tubes and very noticeable in those with halogen lamps.

In fact, the flashing of halogen lamps in those heaters will drive you bonkers! Don't do it.

The mains voltage is only switched as it passes through zero volts (ie, "zero-voltage switching").

This minimises any generation of electromagnetic interference by the controller.

Two versions

As noted, this project can be built in one of two versions, with or without a thermopile sensor for temperature control. If you build it without the optional thermopile sensor, the knob on the front panel will allow you to vary the power over 15 different power levels.

The second version, with the thermopile sensor, provides a non-contact temperature measurement method by detecting the infrared radiation emitted by objects outside the box.

This form of room temperature sensing is ideal since the Heater Controller's circuitry runs at 230VAC mains potential and contact with an uninsulated external sensor would be dangerous.

By having the thermopile located safely inside the unit, with a transparent window for insulation, it is rendered safe and its operation is not affected by self-heating due to internal dissipation, as would be the case with an internal sensor.

The Heater Controller can be used with a 220-250VAC mains supply at 50Hz or 60Hz. It is not suitable for use with 110VAC supplies without some changes being made to the power supply and mains voltage detection circuitry.

As you can see from the photos, the Heater Controller is mounted in a low-profile diecast aluminium case with mains plug and socket leads at one end, along with a fuse holder. The adjustment potentiometer is on the lid.

Features & specifications

- Controls 230VAC heaters up to 10A/2300W.
- Suitable for use with bar heaters, ceramic heaters or oil-filled convection heaters. Not suitable for halogen or fan heaters.
- 220-250VAC mains operation, 50Hz or 60Hz.
- Heating power or Temperature control
- Power control: 15 steps from low to full heating power. 300ms (50Hz) or 250ms (60Hz) cycle.
- Temperature control: 15-31°C in 1°C steps.
- Zero voltage switching for low interference.
- Triac gate drive: 68mA pulse for 300µs after each zero voltage crossing.

Circuit description

The complete circuit for the Heater Controller is shown in Fig.1. We'll start by describing the complete version which provides temperature control.

The circuit is based around microcontroller IC1, Triac Q2 and thermopile sensor TS1.

IC1 provides overall control, driving the sensor and the Triac which connects mains power to the heater.

TS1 has four pins and it actually comprises two separate devices in the package. The thermopile IR sensor is connected between pins 2 and 3 while an

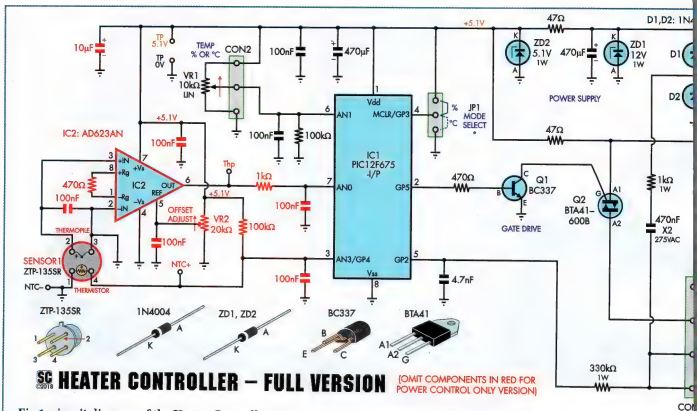


Fig.1: circuit diagram of the Heater Controller. IC1 monitors the mains zero crossing at pin 5, potentiometer setting at pin 6, the internal temperature at pin 3 and external temperature difference at pin 7. It uses this information to decide when to deliver a gate pulse from pin 2, to switch on Triac Q2 which applies one cycle of mains power to the heater at a time.

NTC thermistor is connected between pins 1 and 4.

This is important since the thermopile senses the difference in temperature between the room and the sensor itself.

The thermistor allows us to determine the sensor temperature. By adding the two temperatures, we can determine the absolute temperature of the room.

The microcontroller monitors several signals or voltages, which are internally converted to numbers using its inbuilt 10-bit analog-to-digital converter (ADC).

The voltage across the NTC thermistor in TS1 is monitored by input AN3 (pin 3), while the voltage at the output from instrumentation amplifier IC2 is monitored at input AN0 (pin 7).

The setting of the control potentiometer, VR1, is monitored at input AN1 (pin 6) while the mains voltage is monitored at digital input GP2 (pin 5), via a 330kΩ 1W resistor.

IC1's GP5 output (pin 2) drives the base of NPN transistor Q1. Q1, in turn, sinks current from the gate of Triac Q2, switching it on.

Its gate current flows via the 47Ω resistor connected between the 5.1V supply and the A1 terminal, through the gate and then to circuit ground via Q1.

This is a slightly unusual configuration. The gate resistor (in our case, 47Ω) is normally placed between the Triac gate and transistor collector, with the A1 terminal connected directly to the supply (in our case 5.1V).

However, with that arrangement, noise on the mains Active conductor could be injected into the microcontroller supply and cause it to latch up.

In our circuit, the 47Ω resistor between the mains Active and 5.1V supply provides isolation to avoid this problem while still limiting the gate current in exactly the same manner.

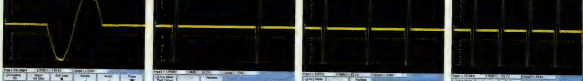
Q2's A1 terminal connects to the incoming mains Active supply via a 10A fuse. Q2 is used as a switch for making power connection from mains Active to the heater, via the A2 terminal.

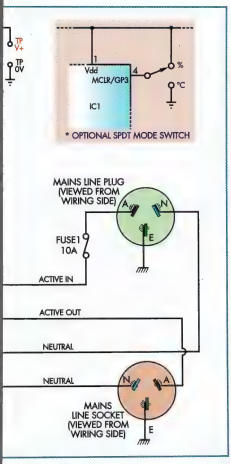
The DC supply for the microcontroller is derived directly from the 230VAC mains supply via a 470nF 275VAC X2 rated capacitor in series with a 1kΩ 1W resistor.

The capacitor's impedance limits the average current drawn from the mains while the 1kΩ resistor limits the surge current when power is first applied.

It works in the following way. When the Neutral line is positive with respect to the Active line, current flows via the 470nF capacitor and diode D1

The first in this series of scope grabs shows the zero-voltage switching action of the Triac. The remainder show how the number of cycles is increased to increase the power.





to the 470µF capacitor to charge it up. On negative half-cycles, the current through the 470nF capacitor is reversed via diode D2.

Zener diode ZD1 limits the voltage across the 470µF capacitor to 12V and that supply then feeds a second 470µF capacitor via a 47Ω resistor and its voltage is limited to 5.1V by zener diode ZD2.

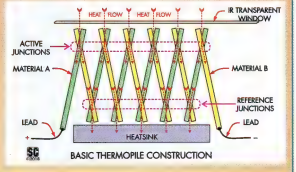
This is the supply for the microcontroller, IC1 and it is decoupled with a 100nF capacitor close to the micro.

IC1 monitors the GP3 digital input at pin 4 and this can be tied to the 5.1V supply or to 0V using a jumper shunt at JP1. When this pin is pulled high, the reading from VR1 is used to control the percentage of full power delivered to the heater.

When this pin is pulled low, the heater is temperature controlled instead, using TS1 for feedback.

What is a Thermopile?

A thermopile is a "pile" of thermocouples that are exposed to the outside via an infrared window. A thermocouple is a junction between two dissimilar conductors, bonded together as shown.



One set of junctions is exposed to infrared energy while the other set is shielded from the infrared and thermally connected to a reference thermal mass. This is indicated as a heatsink in the diagram.

The thermopile we are using has 60 thermocouples connected in series, so their voltages are added together.

The output voltage from the thermopile varies with the difference between the temperature of the infrared-exposed junctions and the heatsink-connected junctions. If the infrared radiation heats the first set of junctions up to the same temperature as the heatsink, then their output will be at 0V.

The output voltage can be positive or negative, depending on whether the heatsink connected junctions are colder (positive) or hotter (negative) than the infrared exposed junctions.

The fact that the temperature measurement is based on received infrared energy means that this is a non-contact method of temperature measurement. All objects which are above absolute zero give off some infrared energy and the hotter they are, the more they emit, hence we can use this energy as a way to remotely sense temperature.

The sensor we are using also includes an NTC thermistor which is joined to the heatsink. This allows the heatsink temperature to be measured. The temperature of the monitored object (ie, the source of infrared energy) is the heatsink temperature plus the temperature measured by the thermopile.

So if the thermopile package temperature is 25°C, as measured by the thermistor, and the thermopile infrared temperature measurement is registering 4°C then the actual temperature measurement is 29°C (25°C + 4°C). If the thermopile registers -3°C then the result is 22°C (25°C - 3°C).

The thermopile includes an infrared-transparent window that allows the infrared energy into the thermopile. We are also using an external lens, to protect against accidental contact with the circuitry on the inside of the box.

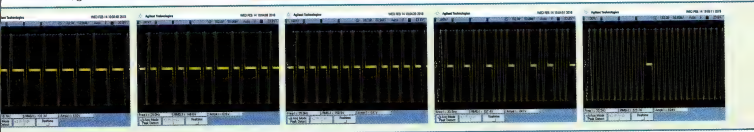
One more thing to note about thermopiles: while we said above that the infrared emissions from an object depend on its temperature and that is true, they also depend on the colour of the object's surface.

A "black body" is an ideal emitter with an emissivity of 1.0 and the thermopile is calibrated to accurately measure the temperature of such objects. All other objects have an emissivity between zero and one and as a result, the thermopile will pick up less infrared energy at any given temperature and so will measure less than their actual temperature.

Examples of objects with low emissivity includes most shiny objects, for example, with polished metal surfaces. To accurately measure the temperature of an object based on infrared energy, you need to know the emissivity and divide the measurement by this value.

In the case of our Heater Controller, the emissivity of a typical room should be high enough, and the difference between internal and external temperature low enough, that such compensation should not be necessary.

We do, however, suggest that you avoid pointing the IR window at very shiny objects.



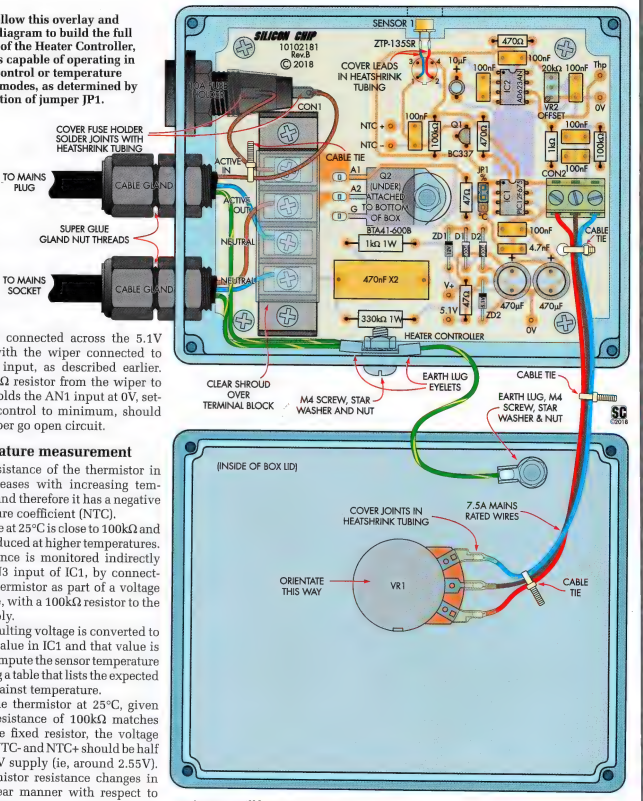


Fig.2: follow this overlay and wiring diagram to build the full version of the Heater Controller, which is capable of operating in power control or temperature control modes, as determined by the position of jumper JP1.

VR1 is connected across the 5.1V supply with the wiper connected to the AN1 input, as described earlier. The 100kΩ resistor from the wiper to ground holds the AN1 input at 0V, setting the control to minimum, should VR1's wiper go open circuit.

Temperature measurement

The resistance of the thermistor in TS1 decreases with increasing temperature and therefore it has a negative temperature coefficient (NTC).

Its value at 25°C is close to 100kΩ and will be reduced at higher temperatures. Its resistance is monitored indirectly at the AN3 input of IC1, by connecting the thermistor as part of a voltage divider, ie, with a 100kΩ resistor to the 5.1V supply.

The resulting voltage is converted to a digital value in IC1 and that value is used to compute the sensor temperature in °C using a table that lists the expected voltage against temperature.

With the thermistor at 25°C, given that its resistance of 100kΩ matches that of the fixed resistor, the voltage between NTC- and NTC+ should be half of the 5.1V supply (ie, around 2.55V). The thermistor resistance changes in a non-linear manner with respect to temperature.

This online calculator can be used to determine how the thermistor resistance varies with temperature, by plugging in a Beta value of 3960 and a resistance at 25°C of 100kΩ: **siliconchip.com.au/link/aaj1**

For example, we can determine that if the sensor is at 15°C, the thermistor resistance will be around 158556Ω, giving a voltage of 3.13V (5.1V x 158556Ω ÷ [158556Ω + 100kΩ]) across the thermistor (ie, at V_{out1}), assuming the supply voltage is exactly 5.1V.

So that determines the temperature of the sensor itself. The thermopile output voltage allows us to determine the difference between the sensor temperature and the room temperature, but it is a very small voltage and needs amplification before it can be measured by IC1.

To achieve this, we use an instrumentation amplifier (IC2). The amplifier gain is set at about 211 by the value of resistor Rg, 470Ω. This amount of gain gives IC2's output a slope of 10mV/°C.

The gain takes into account the losses

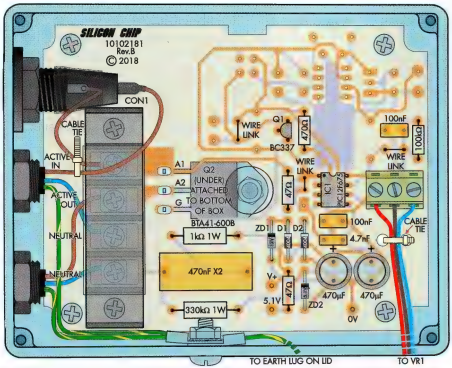


Fig.3: this diagram shows which components can be omitted, to build the unit only for heater power control only. JP1 is replaced with a wire link and two additional wire links are fitted where shown. The photo below is of the full version and shows all wiring completed and secured, as in the diagram opposite.

in infrared heat through the lens used to cover the sensor.

The output voltage of IC2 is referenced against a non-zero voltage so that we can measure the room temperature even if it is colder than sensor TS1.

So if the output from IC2 is at this reference voltage, the thermopile measurement is zero degrees (ie, ambient equals sensor temperature). The reference voltage is set by trimpot VR2 to half-supply, ie, 2.55V.

If the output of IC2 is 20mV above the reference voltage then the temperature difference is +2°C.

The micro adds this differential temperature to the sensor temperature, computed as explained above, to gauge the room temperature.

The negative end of the thermopile (pin 3 of TS1), which connects to the inverting of IC2 (pin 2) is connected to ground.

Thus, the positive output of the thermopile, at pin 2 of TS1, can vary above or below ground, depending on whether the outside temperature is above or below the sensor temperature.

The thermopile is a voltage source and it can generate a negative voltage, despite the circuit not having a negative supply.

However, instrumentation amplifier IC2 is capable of handling input voltages down to 150mV below its negative supply.

The thermopile output voltage is typically within ±1mV so this is not a problem.

The 100nF capacitors at the AN0, AN1 and AN3 inputs of IC1 provide a low impedance source for the analog-to-digital converter's sample-and-hold circuitry.

Zero voltage crossing detection

Pin 5 of IC1 (GP2) is a Schmitt trigger digital input. This monitors the mains Neutral via a 330kΩ resistor and is filtered with a 4.7nF capacitor. An interrupt in IC1 occurs whenever the voltage changes from a high (around 4V) to a low level (around 1V) and also from a low to a high.

That interrupt occurs when the mains voltage swings through zero volts in either direction. The interrupt tells IC1 that the voltage of the mains has just passed through 0V.

This allows IC1 to synchronise gate triggering with the mains waveform. Note that the 4.7nF capacitor at pin 2 introduces a phase lag (delay), but this is compensated for within IC1's software.

The voltage at pin 5 is clamped by IC1's internal protection diodes. They clamp at +5.4V and -0.3V. Since the 5.1V supply for IC1 is essentially connected to the mains Active via the 47Ω resistor, the sensed Neutral voltage is relative to the 5.1V supply.

Controlling power level only

If you only want to be able to control the heater power and don't need temperature regulation, jumper JP1 is set to pull pin 4 of IC1 high. In this case, there is no need to install TS1 or IC2, trimpot VR2 nor any of the associated resistors and capacitors (see Fig.3). This would reduce the cost of

Parts list – Heater Controller

1 double-sided PCB coded 10104181, 103 x 81mm
1 diecast aluminium box 119 x 94 x 34mm [Jaycar HB-5067]
1 Fresnel lens for IR sensor (Murata IML0688) [RS components Cat 124-5980] †
1 M205 10A safety panel mount fuse holder with 10A M205 fuse (F1) [Altronics S5992]
1 4-way PC mount terminal barrier (CON1) [Jaycar HM-3162]
1 3-way PC mount terminal block with 5.08mm pin spacings (CON2)
2 cable glands for 5-10mm cable
1 DIL-8 IC socket
1 3-pin header with 2.54mm spacing and shorting block †
1 2m long 10A mains extension lead
1 knob to suit VR1
4 4mm eyelet connectors
4 8mm long M3 tapped Nylon spacers
3 M4 x 10mm screws
2 4mm ID star washers
3 M4 hex nuts
8 M3 x 5mm machine screws
4 stick-on rubber feet
10 PC stakes †
1 100mm length of 3mm diameter heatshrink tubing
1 25mm length of 6mm diameter green heatshrink tubing, if required for eyelet lugs
3 100mm lengths of 250VAC 7.5A mains wire (for VR1)
4 100mm long cable ties

Semiconductors

1 PIC12F675-I/P microcontroller programmed with 1010418A.hex (IC1)
1 AD623AN instrumentation amplifier (IC2) †
1 ZTP135SR thermopile sensor (TS1)‡ [element14 Cat 2506255]
1 BTA41-600BRG insulated tab 40A 600V Triac (Q2)
[element14 Cat 1057288, RS Components Cat 687-1007]
1 BC337 NPN transistor (Q1)
1 12V 1W (1N4742) zener diode (ZD1)
1 5.1V 1W (1N4733) zener diode (ZD2)
2 1N4004 1A diodes (D1,D2)
Super glue, heatsink compound, solder

Capacitors

2 470µF 16V PC electrolytic
1 10µF 16V PC electrolytic †
1 470nF 275VAC X2 class
7 100nF 63V or 100V MKT polyester ‡
1 4.7nF 63V or 100V MKT polyester

Resistors (0.25W, 1%)

1 330kΩ 1W | 2 100kΩ § | 1 1kΩ † | 1 1kΩ 1W | 2 470Ω § | 2 47Ω
1 20kΩ multi-turn top adjust trimpot (code 203, 3296W style) (VR2)†
1 10kΩ linear 24mm potentiometer (VR1)

(† not required for power control only version)
(§ 1 required for power control only version)
(‡ 2 required for power control only version)

building the unit.

Note that it would be possible to build the unit so that it could be used in either mode, by fitting a 250VAC-rated single-pole double-throw toggle switch to the box and wiring it in place of JP1.

In percentage control mode, the temperature sensed by TS1 would be ignored.

Construction

The Heater Controller is built on a double-sided, plated-through PCB (printed circuit board) coded 10102181 and measuring 103 x 81mm. This is mounted inside a diecast box of 119 x 94 x 34mm.

Fig.2 shows where the components are fitted for the full version, which can regulate the temperature, while Fig.3 shows just the components fitted which are required for controlling the heater power level (percentage).

Follow the overlay diagram appropriate to your version. Start by installing the resistors. Table 1 shows the resistor colour codes but you should also check each resistor using a digital multimeter.

Three additional wire links are fitted for the heater power control only version. These are shown in Fig.3; one to set the mode, in place of JP1, and two to hold the AN0 and AN3 inputs of IC1 at 0V. Use resistor lead off-cuts to make these links now.

Following this, install the diodes which must be orientated as shown. Note that there are several different diode types: standard 1N4004 diodes for D1 and D2, a 12V 1W zener (1N4742) for ZD1 and a 5.1V 1W zener (1N4733) for ZD2.

IC1 is mounted on an 8-pin DIL socket so install its socket now, taking care to orientate it correctly. Leave IC1 out for the time being, though. IC2 is installed for the full version, soldered directly on the PCB. Transistor Q1 can also be installed now.

Fit the capacitors next. The X2 class capacitors and the polyester types usually are usually printed with a code to indicate their value; see the small

* depends on version — Resistor Colour Codes

Qty.	Value	4-Band Code (1%)	5-Band Code (1%)
❑ 1	330kΩ	orange orange yellow brown	orange orange black orange brown
❑ 1/2*	100kΩ	brown black yellow brown	brown black black orange brown
❑ 1/2*	1kΩ	brown black red brown	brown black black brown brown
❑ 1/2*	470Ω	yellow violet brown brown	yellow violet black black brown
❑ 1/2*	47Ω	yellow violet black brown	yellow violet black gold brown

Small Capacitor Codes

Qty.	Value	µF Code	EIA Code	IEC Code
❑ 1	470nF	0.47µF	474	470n
❑ 2/7*	100nF	0.1µF	104	100n
❑ 1	4.7nF	.0047µF	472	4n7

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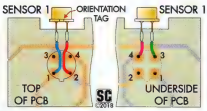
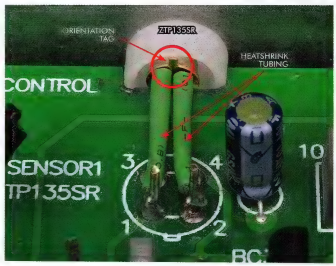


Fig.4: this diagram and the photos at right and below show how the sensor is mounted, with its lens emerging through an 11mm hole drilled through the side of the case.



capacitor codes table. The electrolytic types are marked with their µF (microfarad) value and must be oriented with the polarity shown. The longer lead is positive while the negative end is usually marked on the can with a stripe.

The screw terminals and trimpot can be installed now. The 3-way terminal block for CON2 is fitted with the lead entry toward the lower edge of the PCB. VR2 has its adjustment screw near the top edge of the board, as shown in Figs.2 & 3. If fitting a pin header for JP1, solder this in place now.

TS1 is fitted for the full version and is mounted along the edge of the board. This arrangement is shown in Fig.4. The sensor is located centrally within the cut-out on the side of the board, with the leads to pins 1 & 2 along the top of the PCB and the leads to pins 3 & 4 along the underside.

You can either use PC stakes to connect the lead of TS1 to the PCB terminals or bend the sensor leads to fit into the PCB holes directly. Make sure the leads for pins 1 and 2 do not short to the pads on the PCB for pins 3 and 4; a small piece of electrical tape or heathsrink tubing could be used to insulate them from the board.

Any pigtails on the underside of the PCB, including the ends of PC stakes, must be cut short to prevent contact with the base of the sensor. Leave Triac Q2 to be installed later.

Preparing the case

Now you need to drill some holes in the diecast enclosure. Drilling templates are provided in Fig.5. The lid requires a 9.5mm diameter hole for potentiometer VR1 and a 4mm Earth screw hole so drill them now.

If building the full version, follow the instructions below. Otherwise, go to the heading titled "PCB location".

The first hole that needs drilling in the box base is that for the lens. This is on the side of the box and is 9mm in diameter.

Once drilled, fit the lens into the hole with the two protruding locating prongs on the rear rim of the lens housing both facing downward. Attach three of the four 8mm spacers to the PCB with the screws from the top of the PCB. The omitted spacer can be the one nearest VR2 or near fuse F1.

Now place the PCB into the box with the thermopile sensor entering the lens. While holding the PCB in place, press the PCB toward the lens so that it is held tightly in place.

Align the PCB so it is squarely positioned in the box and mark the mounting hole position for the missing spacer on the base of the box, then drill this hole to 3mm and check that the hole is correctly positioned.

If adjustment is needed, file the hole with a small needle file so it is correctly positioned. Once correct, remove the spacers and lens and place the PCB in the box. Align it with the hole already drilled. When the PCB is squarely positioned, mark out and drill the remaining three holes.

PCB location

Note that when the PCB is in the box, the CON1 screw terminal end of the PCB sits further away from the end of the box compared to the other end. This allows space for the cable gland nuts. Holes for the fuse, cable glands and Earth screw can also be drilled now, making sure these are drilled at the CON1 end of the box.

Re-attach the 8mm long spacers to the PCB. Then bend the Triac leads up at 90°, 4mm from the body of the Triac. Insert the leads into the PCB from the underside.

The PCB can now be secured to the case with the screws from the underside into the tapped spacers. Mark out the Triac mounting hole position on the base of the case. Remove the PCB again and drill to 4mm. Clean away any metal swarf and slightly chamfer the hole edge.

Re-attach the PCB and adjust the Triac lead height so the metal tab sits flush onto the flat surface, then secure the Triac with the M4 screw and nut. Note that the metal tab is internally isolated from the leads and so does not require any further insulation between its tab and case. Solder the Triac leads at the top of the PCB, then trim them short.

Now remove the screws to gain access to the underside of the PCB and solder the Triac leads from the underside. The four rubber feet can be attached to the base of the case now.

The case lid should be fitted with a panel label. We have designed three labels. One is for the power-control only version, one is for a temperature-control only version and the third option is for when JP1 can be used to select either control mode. These label files can be downloaded from our website (www.siliconchip.com.au).

Once the label has been attached, cut out the potentiometer hole and Earth screw hole with a hobby knife.

Wiring

Cut the 10A extension lead in two,

to provide one lead with a plug on the end and another with a socket. Where the lead is cut depends on how long you prefer each lead.

You may prefer a long plug cord and short socket lead, so the heater is located near to the controller. Alternatively, the lead can be cut into two equal lengths. Before cutting though, make sure you have sufficient length to strip back the insulation as detailed in the next two paragraphs.

Strip back the outer insulation sheath by about 200mm on the socket lead so you can get a suitable 100mm length of Earth wire (green/yellow stripe) for the connection between the chassis and lid.

Then cut the blue Neutral wire and brown Active wires to 50mm. Some of the spare 150mm brown wire length can be used later to connect from the fuse to CON1.

The plug lead outer sheath insulation should be stripped back to expose 100mm of wire. This leaves sufficiently long Earth and Active leads. Cut the Neutral wire to 50mm. Pass these wires through the cable glands and connect as shown in Fig.2, stripping back the insulation before terminating to the fuse and CON1.

Make sure the plug lead and socket lead are placed in the correct cable gland and wired as shown. Note that when wiring the fuse holder, heatshrink tubing should be placed over the wire terminals. Heatshrink tubing 3mm in diameter is suitable. Pass the wires through the tubing before soldering to the terminals.

Cut the shaft of VR1 to 12mm long and file the edges smooth. Then attach the three 100mm lengths of 7.5A mains rated wire to its three terminals and cover with 3mm heatshrink tubing. The other ends connect to CON2. These wires are held in place using a cable tie that feeds through holes in the PCB.

Attach VR1 to the lid and note that the potentiometer must be oriented as shown, so it fits beside the mains rated capacitor on the PCB. Fit the knob; you may need to lift out the knob cap with a hobby knife and re-orient the cap so its pointer position matches the rotation marks on the panel. Apply a smear of heatsink compound to the underside of the Triac before installing the PCB inside the case.

Connect the Earth wires to M4 crimp or solder eyelets and cover with green heatshrink tubing. The eyelets attach to the side of the case and the lid using an M4 screw, star washer and nut.

IC1 can now be plugged in, taking care it is oriented correctly. Insert the 10A fuse into its holder. Press the cover onto the terminal barrier (CON1) to prevent accidental contact.

Check your construction carefully and especially check that the Earth wires (green/yellow striped) actually are connected to the case and Earth pins on the mains plug and socket. Check this with a multimeter set to read low ohms. The cable glands need to be tightened to hold the mains cords in place.

Because these are easily undone, the thread of the glands should have a drop of Super Glue (cyanoacrylate) applied to the threads before tightening. This way, the glands cannot be easily undone. Attach the lid using the four screws supplied with the case.

If you fitted the pin header for JP1, now plug the shorting block into the percentage (%) position. Connect a heater to the controller and with the lid in place, apply power and check that the power can be varied using VR1.

The following text only applies to the temperature-control version, so if you built this, unplug the unit, open up the lid and shift the shorting block into the alternative position.

Setting up the thermopile

The reference voltage needs to be adjusted now and this procedure also compensates for any offset voltages present in TS1 and IC2.

Do not plug the unit into the mains directly during this procedure! You will need a supply that is between 5 and 9V DC, (eg, a 9V battery) connected between the 0V PC stake and the V+ PC stake on the PCB.

Monitor the thermopile voltage using a multimeter connected to the 0V (black) and Thp (red) terminals, then adjust VR2 so that the voltage at Thp is half the voltage measured at the terminal that's labelled 5.1V. So for example, if the supply is 5.1V, Thp should be set to 2.55V.

This adjustment must be done when the thermopile is measuring the same temperature as its own body. To ensure this, place a matte black object larger than the diameter of the lens directly in front of it.

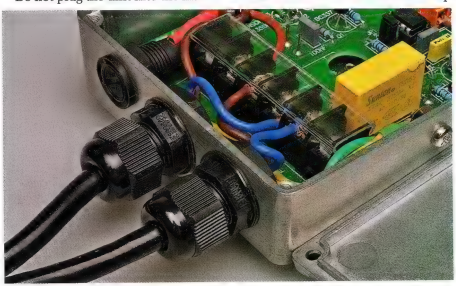
This object needs to be the same temperature as the sensor, so place it nearby and leave it for an hour or so, to ensure that they are very close in temperature.

This black body can be a block of wood painted matte black, the side of a black plugpack, a piece of matte acrylic, black-handled kitchen utensil, etc.

Final calibration

Final calibration is done with the unit powered from the mains, so make sure the lid is in place.

Firstly, measure the ambient temperature with a thermometer and set VR1 to that setting, noting that calibration can only be done if the ambient temperature is within the range of 15-31°C. Switch on the power and after about five seconds, check if the load is on or off. An incandescent lamp



Close-up view of the mains input and output section of the Heater Controller. Don't forget to place the protective shroud over the mains terminal block.

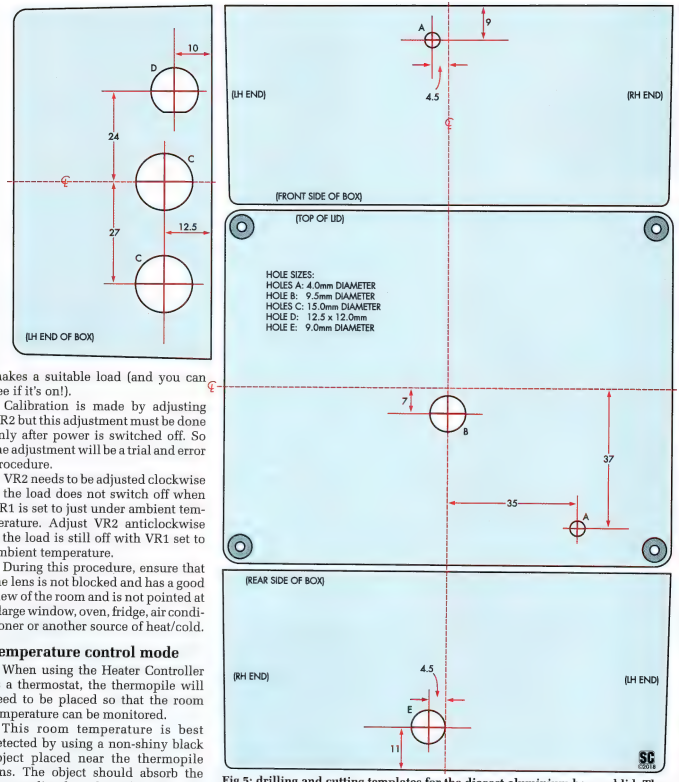


Fig.5: drilling and cutting templates for the diecast aluminium box and lid. The "D"-shaped fuseholder hole should be drilled to 11mm and then filed to the shape shown here, to prevent the fuseholder from rotating.

makes a suitable load (and you can see if it's on!).

Calibration is made by adjusting VR2 but this adjustment must be done only after power is switched off. So the adjustment will be a trial and error procedure.

VR2 needs to be adjusted clockwise if the load does not switch off when VR1 is set to just under ambient temperature. Adjust VR2 anticlockwise if the load is still off with VR1 set to ambient temperature.

During this procedure, ensure that the lens is not blocked and has a good view of the room and is not pointed at a large window, oven, fridge, air conditioner or another source of heat/cold.

Temperature control mode

When using the Heater Controller as a thermostat, the thermopile will need to be placed so that the room temperature can be monitored.

This room temperature is best detected by using a non-shiny black object placed near the thermopile lens. The object should absorb the surrounding heat from the room air, allowing the thermopile to take the temperature reading.

In practice, you may just need to place the controller box and lens near to any object of any colour to have satisfactory temperature control.

The acceptance angle to the thermopile via the lens is about 84°. This can be visualised as a cone projecting out from the lens with an 84° angle at the base. This is close enough to 90° that 100mm from the lens, the area that is observed by the thermopile is a circle of 200mm diameter. In other words, it is a 1:2 ratio of the distance from the lens to the spot size.

Take care not to have the thermopile facing the heater itself. The high infrared level from the heater will cause the controller to switch off the heater. Bar radiator elements can reach 380°C, while convection heaters will be significantly above ambient. SC

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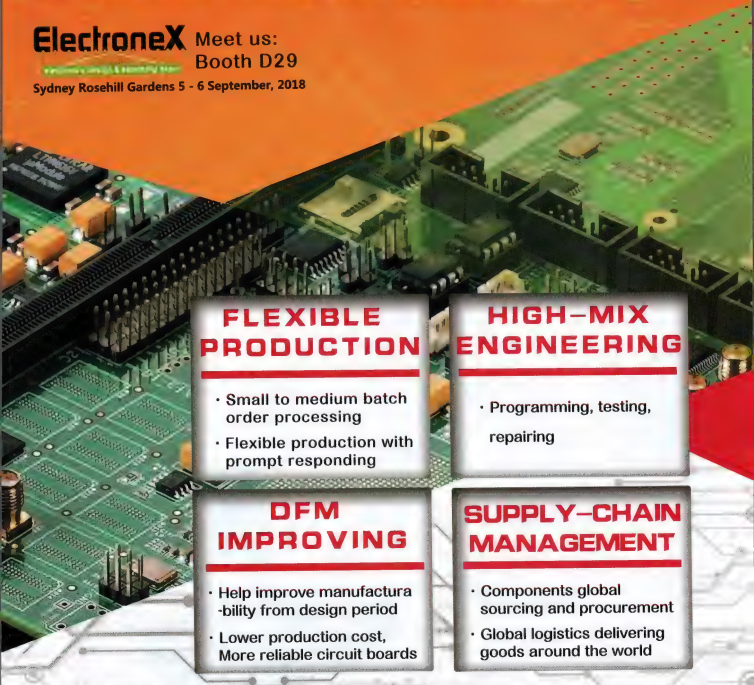

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Three-Axis Arduino Seismograph

By Tim Blythman and Nicholas Vinen

Using a sensitive three-axis accelerometer to log seismic activity over long periods, this Seismograph allows you to detect and analyse distant or close earthquakes. It's a great educational project, easy and cheap to build and it logs seismic activity in all three axes, along with the overall magnitude, to a microSD card.

This "helichart" from a Seismograph operated by the US Geologic Survey (USGS) shows a magnitude 6 earthquake recorded at Guam on February 13th, 2018. One of the disadvantages of this format is that large tremors cause the pen to overwrite other data.

The **Seismograph projects** we have published in the past involved building a horizontal pendulum and then sensing its motion.

However, pendulum designs only respond to waves in one of the horizontal axes and so their sensitivity will vary, depending on where the epicentre of the quake is located, compared to your location.

Waves which are orientated *along* the pendulum would barely register at all. It can also miss vertical waves, such as the S-wave and Rayleigh waves.

(For an explanation of earthquake wave types, see the desctiption in last month's **Earthquake Warning Alarm** – siliconchip.com.au/Article/10994).

In contrast, the 3-axis accelerometer used in this project will pick up vibration with any orientation: up/down, forward/back or side-to-side.

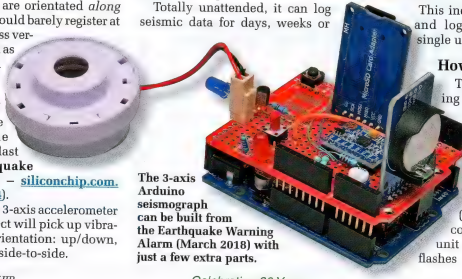
So you won't miss any waves which happen to pass by and you can even determine the type of waves later while examining the data, based on the relative amplitude picked up by each axis.

This one is also much easier to build because it's completely electronic. Another big advantage of this Seismograph, besides its low cost is that it's a stand-alone unit and so don't need your PC to log the data.

Totally unattended, it can log seismic data for days, weeks or even months, and you can simply unplug the SD card any time and load the data onto your PC for analysis when it's convenient.

This is the second Earthquake monitoring project we have published that uses a 3-axis accelerometer. It is a development from the previously mentioned Earthquake Early Warning Alarm project published in our March 2018 issue.

This incorporates both alarm and logging functions in a single unit.



The 3-axis Arduino seismograph can be built from the Earthquake Warning Alarm (March 2018) with just a few extra parts.

How it works

The Earthquake Warning Alarm used an Arduino with an MPU-6050 accelerometer/gyroscope module to detect either P-waves (which have a horizontal component) or S-waves (which have a vertical component). When that unit detects a P-wave, it flashes a LED and sounds a

siren, giving warning about the possibly imminent arrival of the more destructive S-wave and surface waves.

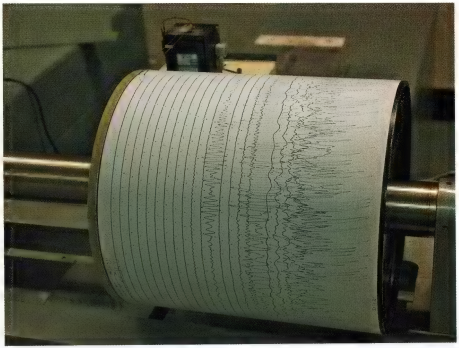
There are many thousands of earthquakes every year – between 12,000 and 14,000 according to reliable data.

But unless you hear about them on the news, you will probably not even be aware of them.

However, they can be detected and you can get some idea of the distance, magnitude and depth of the quake, based on the faint vibrations that you can pick up at your location.

If you want to study the details of a seismic event after it happens, you will need to record even the faintest vibrations and also the time they arrive.

It turns out that this can be done with the same Arduino and MPU-6050 combination we used for the Early Warning Alarm. We just need to add an SD card module to store the data and a real time clock (RTC) module to provide accurate time-stamps.



A helichart Seismogram being recorded at the Weston Observatory in Massachusetts, USA. Note how the arc within which the pen moves causes distortion of the larger amplitude tremors. *Image credit: Wikipedia user Z22.*

Recording the data

In researching this project, it was surprisingly difficult to find a standard data format for recording and viewing raw seismic data with multiple channels.

These days, with MEMS accelerometer chips being readily available, more and more seismographs log data in multiple axes – so it would be logical to standardise on a suitable storage format. Yet this does not seem to have happened.

You may recall seeing images of the old-fashioned drum type seismographs which use a pen and weight to log seismic data onto a roll of paper.

Sometimes, three of these machines would be placed in the same location but with different orientations, to capture all the components of seismic activity, much like we are doing with the three-axis accelerometer.

But when storing the data digitally, it makes sense to store it in a single file, stamped with the time and date that the recording started. That way, all the data can be copied or moved as one unit and you can view all the axes at the same time, to see how the vibrations at different orientations correspond.

We eventually managed to find some software which could handle this type of file but it only seemed to be intended to process seismic data, not view it. The commonly available viewers mostly show just one seismic plot at a time and that just isn't adequate for the task, in our opinion.

Oh, the Audacity!

However, we did find one piece of software – Audacity – that despite not loading specialised seismic data file formats, would open audio (WAV) files.

And that gave us an idea. Audio files can have multiple channels and they log data sampled at evenly-spaced time intervals too.

So why couldn't we store and process seismic data as if it's simply low-frequency audio data?

If you think about it, that's pretty much what it is and this is one reason why earthquakes can involve a lot of noise!

We considered storing the data as a .csv (comma separated value) file, which is easy to analyse but the sheer quantity of data involved in logging day after day would make this awkward.

Viewing seismic data

The output of a seismograph is known as a seismogram and traditionally, this was in the form of a helichart.

This is an abbreviation for helical chart and derives from the fact that the chart would be wrapped around a rotating drum, while the recording pen moves slowly along the chart in a 24-hour period, taking a helical path.

A traditional helichart seismogram is shown above. This appears as a series of lines across the

SPECIFICATIONS

Sensor type:	3-axis, 16-bit accelerometer
Full-scale measurement:	±4g
Resolution:	0.000122g
Practical minimum reading:	around ±0.001g
Frequency response:	0.625 (-3dB) to 21Hz (Nyquist limit)
Sampling rate:	42Hz
File format:	WAV, four channels
Storage medium:	microSD card, up to 32GB
Data rate:	1.2MB/hour, 29MB/day, 10.6GB per year
Maximum recording time:	512 days

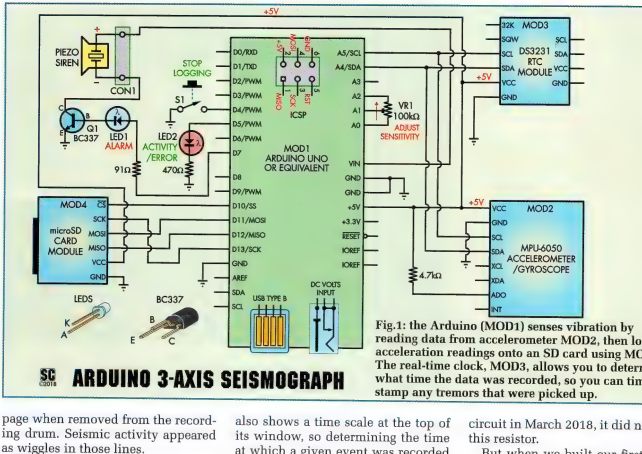


Fig.1: the Arduino (MOD1) senses vibration by reading data from accelerometer MOD2, then logs the acceleration readings onto an SD card using MOD4. The real-time clock, MOD3, allows you to determine what time the data was recorded, so you can time stamp any tremors that were picked up.

ARDUINO 3-AXIS SEISMOGRAPH

page when removed from the recording drum. Seismic activity appeared as wiggles in those lines.

Nowadays, the helichart is generated by a computer, and the lines are horizontal rather than sloping.

So, that brings us back to the .wav file format and Audacity.

Although designed for sound, it is well suited to any sort of data that can be represented as a waveform. Typical wave files will be one or two channels (ie, mono or stereo), but the .wav format can theoretically support thousands of channels.

As mentioned above, we're using four channels to record our data: separate X, Y and Z channels and a combined magnitude of all channels.

Its display is much like that of a helichart. Some other applications may not handle .wav files with more than two stereo channels but we found Audacity handles them well.

You could play the file back as audio but the sound is not very interesting. Unless a seismic event is very close (ie, close enough for you to feel), you will need to amplify the data greatly to get anything remotely audible, and given the low frequencies involved, you will probably have to speed it up as well.

But what Audacity does very well is let you view the data, scroll around and zoom in to view events. Audacity also shows a time scale at the top of its window, so determining the time at which a given event was recorded is straightforward (see Fig.4).

You can also easily cut out an interesting section of data and save it into a separate file for further analysis later.

Circuit details

The circuit diagram of the Seismograph is shown above.

The MPU-6050 Accelerometer module (MOD2) communicates with the Arduino (MOD1) via an I^2C bus, using the SDA (data) and SCL (clock) pins.

The micro sends set-up commands and then periodically retrieves acceleration readings over this bus. MOD2 runs off the same 5V supply as the Arduino.

In contrast, SD card module MOD3 is wired up to the SPI interface on the Arduino, which is on pins D10-D13 while the real-time clock module, MOD4, connects to the same I^2C interface as the accelerometer (MOD2), ie, the SDA and SCL pins.

Because the SDA and SCL functions on the Uno are shared with analog pins A4 and A5, you can't use these as analog inputs when you're using I^2C.

You may be wondering why there is a 4.7kΩ pull-up resistor from the ADO pin on MOD2 to +5V. If you look at our Earthquake Early Warning alarm circuit in March 2018, it did not have this resistor.

But when we built our first prototype, we were mystified to find that as soon as we had wired up the RTC module, the accelerometer/gyro module stopped giving valid data. This was even before we'd added any new code to query the RTC module.

We spent quite a while troubleshooting before deciding to check the default I^2C addresses of these two modules.

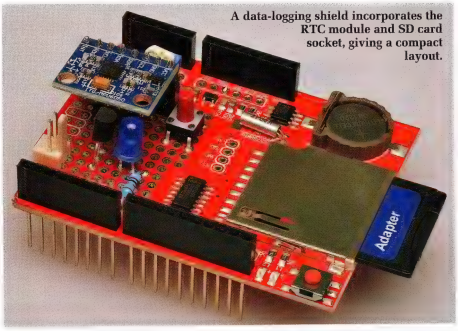
Surely, out of the 127 possible addresses, they would not have chosen the same one? The DS3231's address is fixed at 68 hexadecimal. So we looked up the MPU-6050 default address. Hard to believe but it's true – it was 68 hex too.

Luckily, the MPU-6050 does give you the option to change the address to 69 hex, by pulling the ADO line high.

So that's why we added the 4.7kΩ resistor in this way; to allow the two units to share the sole I^2C bus that the Arduino provides.

Another small change we had to make was to change the pin controlling the alarm LED and siren from D12 to D7, as using D12 interferes with the SPI bus on the SD card.

If you're building this project as a seismograph and you don't need the alarm function, you can leave these



A data-logging shield incorporates the RTC module and SD card socket, giving a compact layout.

components off but they're inexpensive so we figured it was worthwhile to leave them in.

We've also added a second LED (LED2) to give status information about SD card errors which would stop data being recorded. It's pulsed on briefly when writing to the SD card, to give a visual indication that the unit is working. It's driven by digital output D5.

Note that we also briefly pulse LED1 if LED2 is flashing to indicate an error writing to the card, for example, if it's full. This results in a periodic chirp from the siren, alerting you to the fact that the unit needs attention.

There's also tactile push-button S2, sensed by digital input pin D4, which you can use to stop logging to the SD card. You can then safely remove it without corrupting the data.

In operation, the Uno reads the acceleration data from MOD2, runs it through the filtering algorithm (to remove the force of gravity and so on) and after reading the current time from RTC MOD3, saves the data and time to the SD card using MOD4.

The data saved in the file is the separate X, Y and Z accelerations in units of g and also an overall acceleration magnitude which is computed using an RMS algorithm.

The time and date are stored in the file name of the WAV file itself. A new file is created at midnight and its file name will contain the date. When you open the file in a program like Audacity and are viewing the data, because it displays the time from the start of the file, this will correspond to the time that the data was recorded.

Having written the data to the SD card, the Uno then checks the filtered acceleration values to check if a P-wave or S-wave has been detected, and activates the alarm as necessary.

The cycle is repeated 42 times per second but writes do not necessarily occur to the SD card this frequently. Rather, they are buffered and flushed once per second, so you can expect about 2-3 block writes per second to occur.

At the same time as it's logging data, the Arduino code is checking the serial port for user input. This is because we've incorporated a function to set the date and time manually over the serial console.

This allows you to ensure the real-time clock is set properly, so your logged data will be accurately time-stamped.

If at any time an SD card fault is detected, the routine stops and LED2 flashes.

You will need to correct the fault (eg, insert a fresh and empty microSD card) and press the Arduino reset button to resume logging.

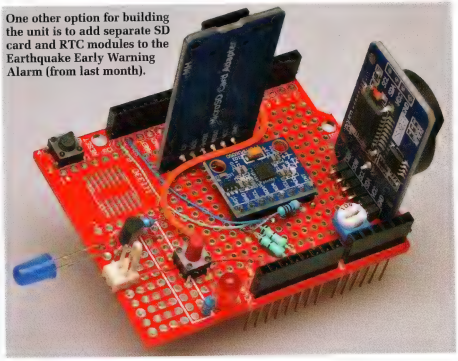
Similarly, to remove the card, press S2, remove the card, then insert a new card and press the reset button to resume logging.

Construction

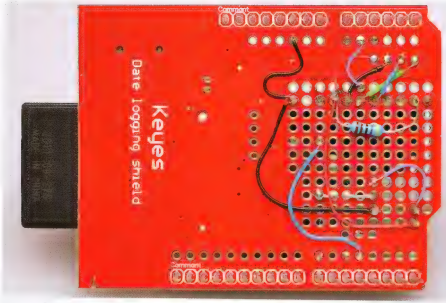
There are two ways you can put it together. We've tested both approaches and they give the same result.

The first method is the same as used in the Earthquake Warning Alarm and that is to solder the three separate modules (MOD2, MOD3 and MOD4) to a prototyping shield and then plug this into the main Arduino Uno (or compatible) board – see below.

The other approach is to use a data logging shield like the Jaycar XC4536 or Altronics Z6380. These shields already have the RTC module and SD card module built in. They also have a prototyping area where you can solder



One other option for building the unit is to add separate SD card and RTC modules to the Earthquake Early Warning Alarm (from last month).



Again shown larger than life size, this photo of the back of the data logging shield PCB shows where the wire links and single 470Ω resistor are located.

the remaining parts.

The latter solution is probably simpler, but the DS1337 RTC used in these shields is not quite as good a the DS3231 real-time clock module.

And depending on where you get the parts, it may end up costing more (although probably not by very much).

If you have already built the Earthquake Early Warning Alarm, to add the extra functions, detach the protoboard from your Arduino and move the 91Ω resistor from pin D12 to D7, to free up the SPI pins. Then add the 4.7kΩ between the ADO and VCC pins of MOD2.

Now you need to add red LED2, its current-limiting resistor, push-button S2 and modules MOD3 and MOD4. Connect LED2's anode to pin D5 and then solder the 470Ω resistor between its cathode and GND. We used the large GND strip in the corner of the protoboard.

Tactile switch S2 is connected between pin D4 and GND, again using the large GND strip. Make sure you use the right pair of pins since some of the pins will be permanently connected internally. Use a DMM set on continuity mode to check which pins are shorted when the button is pressed.

The two new modules are added last. MOD3, the RTC module, can be conveniently placed near the I^2C pins on A4 and A5, which avoids piggybacking wires onto the existing connections for MOD2. This is possible because on an Arduino Uno board, A4 is connected to SDA and A5 is connected to SCL, so these pins have the same function.

The connections for MOD3 are similar to those for MOD2: 5V to VCC, GND to GND, A4 to SDA and A5 to SCL.

MOD4 is connected to the power rails and SPI pins, with D10 being used as CS/SS (chip select/slave select). Connect VCC to 5V, GND to GND, MOSI to D11, MISO to D12, SCK to D13 and CS to D10.

Ideally, MOD4 should be placed as near these pins as possible to keep the wires short. The SPI interface needs to run very fast, and you may get issues with the SD card if the wires are too long.

The final assembly step is to reconnect the assembled board to MOD1.

Building it from scratch

If you're building the Seismograph using separate modules on a protoboard, use the following instructions. Otherwise, jump to the section below titled "Using a data logger shield".

Start by soldering the three modules onto the protoboard, near the pins which they need to connect to. Refer to our photos and the circuit diagram to determine where they should go. You will need to solder the supplied 8-pin header to the MPU-6050 accelerometer board.

You can solder an 8-pin female socket to the protoboard to make it easily removable, or simply solder the other end of the header to the shield.

Solder the 4.7kΩ resistor adjacent to the header for MOD2, between the VCC and ADO pins, then connect it to those pins. Use zero ohm resistors or wire links to connect the four main pins of MOD2 to the Arduino pins: VCC to +5V, GND to GND, SCL to either A5 or SCL and SDA to either A4 or SDA.

If you want to retain the Early Warning Alarm function, you will need sensitivity adjustment trimpot VR1.

This can be soldered directly next to the A0/A1/A2 pins and then wired up to those pins in the most direct manner.

To retain the alarm function, you will also need to wire the piezo siren up to the board, either by soldering its leads directly or via a plug and socket.

Wire the positive lead directly to the VIN pin on the Arduino

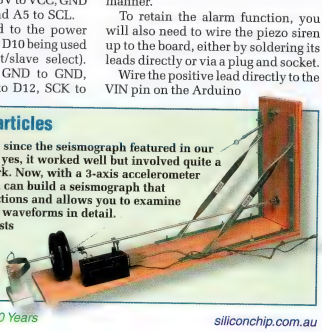
Previous Seismograph and Earthquake related articles

Build your own Seismograph
by Dave Dobeson. September 2005 – siliconchip.com.au/Article/3173

Revised Seismograph
by Dave Dobeson. February 2013 – siliconchip.com.au/Article/2364

Earthquake Early Warning Alarm
by Allan Linton-Smith and Nicholas Vinen. March 2018 – siliconchip.com.au/Article/10994

We've come a long way since the seismograph featured in our September 2005 issue: yes, it worked well but involved quite a deal of mechanical work. Now, with a 3-axis accelerometer and Arduino UNO, you can build a seismograph that works in all three directions and allows you to examine the various earthquake waveforms in detail. And the best part? It costs very little to build – particularly if you already have the Arduino UNO!



and the negative lead to the collector of Q1; the bottom of Fig.1 shows which pins of Q1 are which. Wire the emitter of Q1 to a convenient GND point.

Next, solder the cathode of blue LED1 to the central (base) pin of Q1 and then solder its anode to a 91Ω resistor, with the other end to Arduino pin D7.

Now follow the steps listed above, immediately under the Construction heading, to fit the remaining components which are unique to this design.

Using a data logger shield

The data logging shield version of the Arduino Based Seismograph is probably an easier way to build this unit from scratch, as MOD3 and MOD4, along with red LED2, are already on-board.

Start by adding a wire link (eg, a resistor lead off-cut) between the pins marked 5 and L1. This connects the on-board LED and series current-limiting resistor to pin D5 on the Uno. Solder one leg of the 91Ω resistor from pin D7 to the anode of LED1, then connect LED1's cathode to Q1's base (middle pin).

This can be done by placing the components near each other as shown in the photos, and trimming the legs slightly longer than necessary. The legs can then be bent until touching and soldered together.

The next few connections should be made with some short lengths of insulated wire, and we found it easier to run the wire underneath the shield. The emitter of Q1 is connected to GND, and its collector to the siren's negative lead (or to a polarised plug for the siren, if fitted).

The siren's positive lead is connected to the shield's 5V supply.

If you are using a siren which can run from more than 5V, this can be taken to VIN instead, which is fed from the DC jack on the Uno.

The tactile switch is mounted next and it will need to be right against the edge of the prototyping area on the shield to allow space for MOD2. Connect one side of the switch to GND and the other to D4.

Fit MOD2 next. We used a short length of female header strip to make the module removable and this also allows it to easily clear LED1 and Q1. You could solder it directly to the shield if you have space. Regardless, place the accelerometer assembly on the board before soldering, to check that everything will fit.

Use short lengths of wire to connect MOD2 to the shield, with VCC to 5V, GND to GND, SDA to SDA and SCL to SCL.

There's a small pad with these four connections in one corner of the shield, which makes these connections tidy. The only thing to watch is that SDA and SCL are reversed between the two, so these wires will have to cross.

Now add the 4.7kΩ resistor between ADO and VCC on MOD2. The final component is trimpot VR1, which neatly slots into the pads for A0 and A2. Use a wire link to connect the middle leg to A1.

Now double check all the wiring and

Parts list – Arduino 3-Axis Seismograph

1 Arduino Uno or compatible board (MOD1)
1 Arduino data logging shield (LED2/MOD3/MOD4) [Jaycar XC4536 or Altronics Z6380] **or** see below
1 MPU-6050 based accelerometer/gyroscope module (MOD2) [Altronics Z6324]
1 small plastic box (eg, UB5 Jiffy box; optional)
1 1-13V loud piezo siren [Altronics S6115]
1 100kΩ mini horizontal trimpot (VR1)
1 2-pin polarised header and matching plug (CON1; optional)
1 USB power source (eg, USB charger or computer with free USB port)
a few short lengths of light-duty hookup wire

Semiconductors
1 5mm blue LED (LED1)
1 BC337 NPN transistor (Q1)

Resistors (.25W, 1%)
1 91Ω *(code white brown black brown or white brown black gold brown)*
1 4.7kΩ *(code yellow violet red brown or yellow violet black brown brown)*

Additional parts if not using data logging shield
1 Arduino prototyping shield
1 5mm red LED (LED2)
1 DS3231 real-time clock and calendar module and button cell (MOD3) [Silicon Chip Online Shop Cat SC3519]
1 microSD card interface module (MOD4) [Silicon Chip Online Shop Cat SC4019]

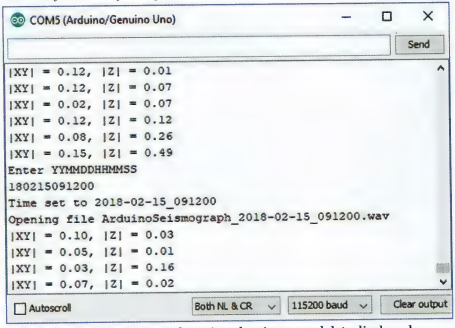
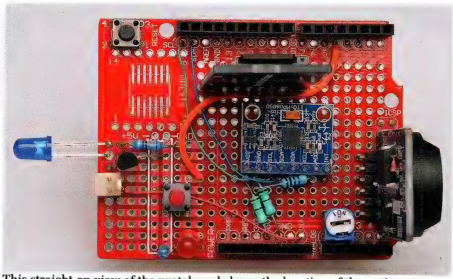


Fig.2: the output from the serial monitor showing normal data display, along with the time and date being set. Time setting mode is entered by pressing the "~" key.



This straight-on view of the protoboard shows the location of the various components and connections. This is a little different from the board shown last month as it also has the microSD card adaptor module (centre top) and the DS3231 RTC module (lower right), both mounted vertically to the protoboard.

plug the assembled shield into MOD1 (the Arduino Uno board).

Programming it

If you haven't already done so, download and install the Arduino IDE from www.arduino.cc/en/main/software. There are a number of libraries that need to be installed to support the RTC module and SD card module. Two of these are easily added by the Library Manager feature, which is only available from IDE version 1.6.4 but we will also supply them in the software download package (as ZIP files).

If you don't have this version, unzip the three library folders into your Arduino libraries folder. This is usually found in your Documents folder, under Arduino/libraries. You may need to restart the IDE after adding the new libraries, but this usually is not necessary.

To use the Library Manager, go to Sketch → Include Libraries → Manage Libraries and search for "rtclib", click the version by "Adafruit" and click install (see Fig.3). Do the same for "SdFat" and install the version by Bill Greiman.

With the libraries installed, open the sketch file, connect the Uno to the computer via a USB cable and click Sketch → Upload.

If the compile and upload do not complete successfully, check that the libraries are in the correct place and properly installed. Also, check that you have the correct COM port selected in the Tools menu.

Now open the Serial Monitor (Tools → Serial Monitor or Ctrl-Shift-M) and check that the baud rate is set to 115200. This will give detailed error messages if there are problems and also allow you to set the time accurately.

Set-up

You might notice that the red LED is flashing in groups of two. This is because it has not been able to detect the card (presumably, you have not inserted it yet). Disconnect the Uno from the computer and install an SD card or microSD card as appropriate. The card should be formatted with FAT16 or FAT32. Re-connect the Uno and restart the Serial Monitor.

If the Serial Monitor is showing a

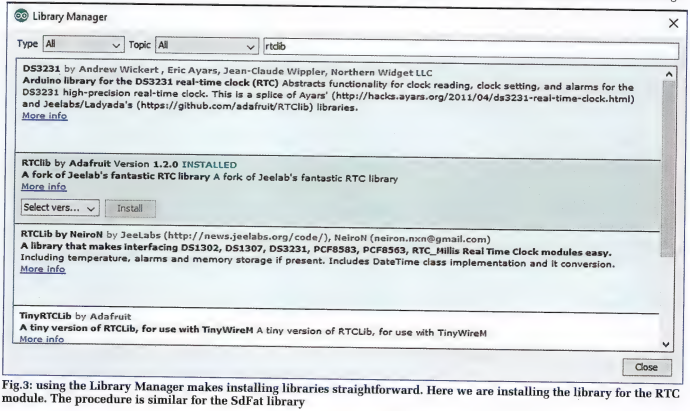


Fig.3: using the Library Manager makes installing libraries straightforward. Here we are installing the library for the RTC module. The procedure is similar for the SdFat library

stream of |XY| and |Z| values, like that shown in Fig.2, then everything is working as it should be. The blue LED should light up if the unit is picked up and shaken, and you should also see the values in the Serial Monitor change. Now is a good time to adjust the alarm sensitivity.

Clockwise on VR1 is more sensitive, so turn VR1 fully clockwise then turn it slowly back until the blue LED just stays off (remembering the alarm condition persists for a few seconds when triggered).

If you find the red LED is still flashing, count the number of flashes in each group. If you are getting one flash at a time, the Uno could not detect the RTC module. Check that the wiring to the RTC module is correct. Any more than that indicates a problem with the SD card.

If you are getting two flashes and the card is installed, check the wiring to MOD4. If you are getting three or more flashes, the card is being detected but cannot be written to. This may be a corrupted or full card.

We've found that the unit generates about 30MB of data per day, so even a 1GB card will last a month without filling up.

FAT16 has a restriction of 512 directory entries, which should give over a year of operation.

Using it

When you want to remove the SD card to examine the logged data, press tactile switch S2 and the red LED will light continuously. This indicates that the SD card has been shut down safely and the Seismograph can be powered down without corrupting or losing data. If you are simply changing to another card, you can remove the old card, insert a new card, then press the Arduino reset button to resume logging.

The files are stamped with the date and time that logging started and a new file is created at midnight.

As mentioned above, you can set the time and date via the Serial Monitor. This is done by sending a '~' character to the Uno, which will cause it to pause logging and wait for an input.

The input is of the form YYMMDDHHMMSS, and should just be digits. For example, for 3:30pm on March 15th, 2018, enter 180315153000. Remember that you have to press 'Enter' for the Arduino Serial Monitor to send the data.

The simplest method is to uncheck the "Autoscroll" option on the Serial monitor, then type ~ and press enter. Type the twelve digits for the time and date and press enter as soon as the actual time matches exactly what you have entered.

You should see a message that the time has been changed and a new file is created starting at the current time. See Fig.2 for an example of this.

Locating the unit

The seismograph can be fitted in an appropriately-sized Jiffy box if desired or it can be operated as-is.

But it should be mounted somewhere solid, away from doors and not on top of a desk or other piece of furniture which can either be bumped or will easily transmit footsteps, vibrations from traffic or other non-seismic sources of vibration.

Perhaps the best place for it would be on top of a concrete slab in a basement. If you don't have a basement, it could be mounted on a solid ground-floor wall (away from doorways) or kept on the floor in an out-of-the-way place (eg, a closet).

This will maximise seismic pickup while minimising other sources of vibration.

On the other hand, maybe you're interested in seeing artificial sources of vibration, such as passing traffic, in which case you may want to deliberately mount the unit near a road. It's up to you!

Try to avoid placing it on any soft surfaces which might absorb seismic energy, such as carpet or vinyl flooring.

Viewing the files using Audacity

Audacity is available as a free download from www.audacityteam.org/download/. The WAV files created by the Seismograph have four channels and can be viewed (and even played) in Audacity. Note that under normal circumstances, the data will simply look like a flat line unless you amplify it since if the unit is picking up any tremors, they are likely to be quite weak.

We actually couldn't see any activity at all until we amplified the waveforms by 20dB, after which we could see movement starting about the time we came into the office in the morning (truck traffic on the nearby road would have increased at around the same time).

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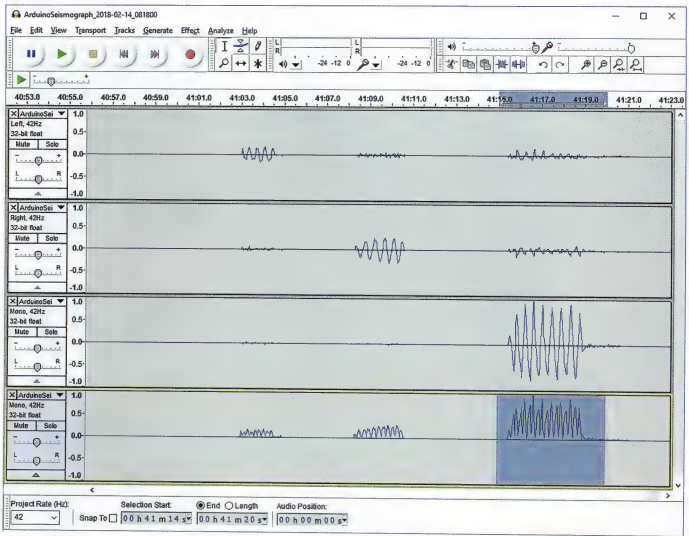

Fig.4: a Seismogram displayed in Audacity. Note the time code along the top of the window. The unit was shaken three times and you can see how the movement was picked up by different combinations of the three axes. The first shake was side-to-side, the second forward/back and the third up/down. All register in the bottom (combined) trace.

Note that Audacity will display the traces with a vertical scale from -1.0 to +1.0 while the data actually represents g-forces of -4.0 to +4.0. So you will need to multiply any readings taken off the vertical scale by a factor of four, to convert them to gs. By the way, we suggest after opening the WAV file, you use the View → Fit Vertically option (CTRL+SHIFT+F) to expand the display.

The first channel, normally labelled "Left", is actually the X-axis reading from the accelerometer, while the second "Right" channel is the Y-axis. A small diagram printed on the top of the Altronics Z6324 module indicates the orientation of the X-axis, with the arrow pointing towards in direction of acceleration which will result in positive readings. Similarly, the Y-axis is shown on the board.

The Z-axis is the third channel, by default labelled "Mono" and indicates up-down motion of the accelerometer, with forces pushing it down being positive (ie, in the same direction as gravity).

Since the fourth "channel" of the recording (also labelled "Mono") constitutes the magnitude of the three-dimensional force vector, that means it is effectively rectified, ie, the value shown will always be between 0 and 1, corresponding to a force of between 0 and 4g. The advantage of this data is that it's guaranteed to pick up vibrations regardless of their orientation relative to the unit.

If you see anything interesting in the plot and want to zoom in and examine it, all you need to do is move your mouse cursor over that area, hold down the CTRL key and rotate your scroll wheel up.

It will zoom in and expand that section of the recording. Rotating the scroll wheel in the opposite direction will allow you to zoom back out.

We suggest initially, you use the USGS Earthquake map at **https://earthquake.usgs.gov/earthquakes/map/** to locate recent earthquakes in your part of the globe and then estimate when they would have arrived at your location, based on a speed of around 3-8km/s.

You can then check your seismogram files to see if you picked up the tremors.

If you can't see anything, try amplifying the signal in a 30-minute window surrounding that time by successively large dB values (by dragging a selection over that time period and using the Effect → Amplify menu option) until you can see the tremors.

Once you've found a few earthquakes in this manner, you will know what to look for in future. **sc**

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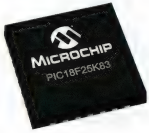

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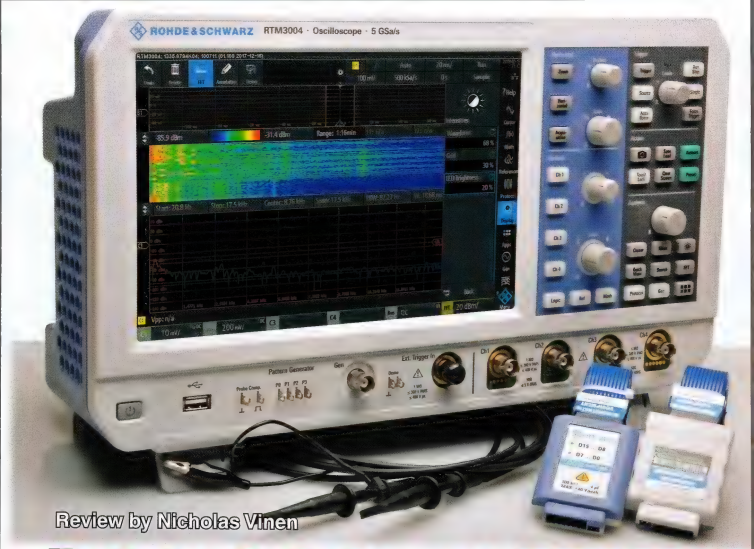


Review by Nicholas Vinen

Rohde & Schwarz RTM3004 Mixed Signal Oscilloscope

Until recently, unless you had a lot of money to spend, you had to decide whether you wanted a scope with good vertical resolution and low noise (for examining low-level signals) or high-speed performance (for high-frequency or rapidly changing signals). Now you can have both, with the Rohde & Schwarz RTM3004.

If you have seen the recent ads from Rohde & Schwarz, you will have noticed that they have released a number of new scopes and that most of them share a single distinguishing feature: their use of a 10-bit analog-to-digital converter (ADC) for better vertical resolution.

Typical digital scopes use an 8-bit high-speed ADC. That means they can sense 2^8 or 256 different voltage levels in any given range. The 10-bit ADC used in many of the latest Rohde & Schwarz scopes has 1024 distinct voltage steps – a significant increase.

This is especially useful when you consider that your standard high-bandwidth oscilloscope probe has a 10:1 division ratio. This is necessary to allow the probe to be properly compensated so that it has a reasonably flat frequency response up to the scope's -3dB point (ie, its rated bandwidth).

So if you're probing a 100mV signal with the standard set of probes, you get just 10mV at the input connector.

If the original signal amplitude is already low and the scope has an 8-bit ADC, you may get a very small "jagged" trace, so it can be difficult to make out the shape of the signal. With a 10-bit ADC, you have four times as many steps and the waveform shape is much clearer and cleaner, as you will notice in our screen grabs.

However, a scope's own noise is also an issue when examining low-level signals. The RTM3004 has a slightly better-than-average noise level, so you

Fig.1: each trace shows one of the pattern generator outputs, set to produce a rolling binary counter incremented at 10MHz. Here you can see the five different bandwidth options that were selectable for each channel of our 500MHz bandwidth demo scope.

Fig.2: this demonstrates that you can have up to eight user-configurable measurements at the bottom of the screen, in this case, peak-to-peak voltage and frequency for each channel. Colour coding helps easily identify which measurement is for which channel.

can often take advantage of the extra vertical resolution. But sometimes the noise still gets in the way.

Five different bandwidth limiting options were provided on the 500MHz model we tested, from 20MHz up to the full 500MHz. That lets you choose a good tradeoff between bandwidth and noise, depending on the signal you are measuring (see Fig.1). This is a welcome feature.

In terms of waveform capture rate, the RTM3004 compares well with its competitors, handling up to 64,000 waveforms per second at up to five gigasamples per second. It also has a very large 40Mpoints per channel of memory depth.

You can expand that to 80Mpoints on the 4-channel model, if you're only using two channels. That's truly massive and you can capture data on a long time-scale and then zoom right in to see the details.

First impressions

Besides the high vertical resolution, one of the first things we noticed when switching on the scope is that coming out of standby and into full operation only takes about ten seconds; quite a bit faster than some of the other scopes we've used. It's also very quiet during operation, with barely audible fan noise.

Another nice feature of this scope is the high-resolution touchscreen. It's very sharp and clear and you can see a lot of detail in the traces and labels. But it lacks an anti-glare coating, so you can see your reflection on the screen, along with whatever happens to be behind you (a window etc). That can make it harder to make out the actual display. But if you use it in a dimly lit room, it's very good.

This unit makes good use of the large amount of screen space available on the 1280 x 800 pixel, 10-inch (25cm) display.

Most of the screen is filled with the graticule, giving the maximum amount of space for traces. Menus pop out as necessary but you can easily make them disappear to get the screen real estate back. The wide aspect works well, giving twelve time divisions and 10 voltage divisions.

Measurements

The RTM3004 lets you put eight measurements of your choice at the bottom of the screen. Far better than the four or five of most other scopes.

This may seem like a minor point but when you're using all four inputs, it can be a godsend (see Fig.2). Measurements are chosen from a menu of clear icons (Fig.3). It's a small thing but it's one of our favourite features of this scope.

A bonus measurement feature is that each measurement can be "gated" within a specified time period so that the result only depends on the values within that time period. The time period can be defined as any subset of the 12 graticules shown on the display, based on either percentage or time delay and each measurement can be based either on the gating period or the full screen.

When using gating, a blue highlighted box appears behind the traces for that period, so you can see how the measurements relate to the traces on the display (see Fig.4).

Illuminated buttons

The colour-changing illuminated buttons on this scope are a great idea. The vertical controls (voltage range, etc) change colour to match the colour coding of the currently selected channel. Similarly, the trigger source button colour matches the channel which is currently being used as the trigger source. Pressing that button cycles the trigger source through the available channels too.

But the default brightness of the illuminated buttons is quite dazzling. Happily, the menus provide the ability for you to adjust the button brightness. And at the minimum setting of 20%, they're a lot less dazzling in anything but the most brightly lit workspace.

It's a pity that you can't turn them down lower because a setting of 10% would probably be ideal in our office. At 20%, the contrast between the lit and unlit buttons makes it hard to read the labels on the unlit buttons.

Now, on any DSO, when you have the trigger mode set to "normal" (not "auto"), it's quite common for the scope to stop triggering if the input signals change. And if you had a steady signal up to that point, it won't be immediately obvious that the scope is no longer triggering and updating its screen.

But Rohde & Schwarz have added a timer near the upper-right corner of

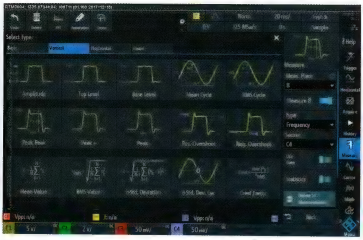


Fig.3: one of four menus showing the available measurements. The menu at right shows that you can select a measurement position (1-8), measurement type (from the menu), source channel, whether to use the gating period and whether to display statistics (max/min/average).

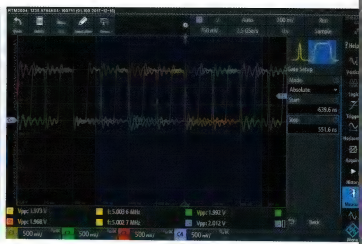


Fig.4: any set of (or all) measurements can be "gated" by a time period which is a subset of the current period being displayed by the scope. This is the area shown in blue and it can be defined as either a proportion of the display or by the start and end delay, as shown here.

the screen. When triggering normally, this area reads "Trig" but if triggering stops, it changes to read "Trig? 1s" and the time counts up. So it's obvious that triggering has stopped and you can see at a glance how long the display has been static. It's a small feature but one we found ourselves using quite often.

User interface

Overall, we'd have to say that the user interface on this scope is probably the easiest that we have used and is very intuitive. That's largely because Rohde & Schwarz have abandoned the idea that all functions need to be available via dedicated buttons and you now need to use the touchscreen for many operations.

That means they were able to simplify the button layout and it also makes it a lot more obvious how to carry out most tasks. The tradeoff is that you will probably need to clean your fingerprints off the screen regularly. But that's a small amount of extra effort in exchange for making the scope easier to use.

One more nice aspect of the interface is the "toolbar" at upper left, with icons giving you access to commonly used functions.

There's a small settings button at top-middle which lets you select which icons appear in this toolbar (see Fig.5). This allows you to populate the interface with buttons to features you frequently use.

One small criticism that we have of the user interface is that it has unnecessary animations when you press buttons.

For example, the menu at the right-hand side of the screen "slides" in and out. That takes time and we're often ready to press a button before it's actually visible. It would be nice to have the option to be able to turn off animations, to make the interface a bit more snappy.

While the interface is quite responsive, there are occasions when there is a short delay between pressing a control and having it take effect. It isn't a big problem but it does fall slightly short of our expectations for the responsiveness of a high-end scope.

The USB and Ethernet control sockets are on the back, plus power and an auxilliary output. The 16 digital inputs are on the right side of the scope, which is convenient since it means the ribbon cables don't get in the way in mixed signal mode.

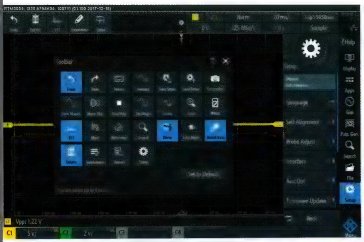


Fig.5: these icons can be displayed on the "toolbar" at upper left so that you can select the option at any time. The currently visible icons are shown in blue and as indicated on-screen, you can have up to eight shown. This menu is accessed using the button just above the yellow trigger marker.

Fig.6: configuration for the pattern generator option. Like most aspects of the scope, when you're adjusting its settings, the menu pops out from the right-hand side of the screen. When finished, it can be hidden simply by pressing the "menu" button in the lower right-hand corner.

Options

The RTM3004 has a number of extra cost software and hardware options which can add features to the scope.

Besides the bandwidth (upgradeable to 1GHz) and 16-channel logic analyser (MSO) option, these include serial triggering and decoding for a range of protocols, history and segmented memory, spectrum analysis, power analysis and an arbitrary waveform/pattern generator.

The configuration menu for the pattern generator is shown in Fig.6. Some of these options (eg, the pattern generator and power analysis) provide built-in "apps" which can be launched when needed.

A number of these options, including all the serial decoding/triggering options, history/segmented memory, spectrum analysis, power analysis and generators can be purchased in a bundle (RTM-PK1) which costs a lot less than paying for each option individually.

The pattern generator is quite useful, especially in combination with the serial decoding and triggering options as it can be used to generate serial test data, eg, to send to a DAC. You could then use the scope to observe the corresponding DAC output.

Other features

We don't have space in this review to list all the other features of the scope. It has pretty much everything else that you would expect (or can think of, really).

It supports mask and limit testing, segmented memory, digital voltmeter, probe sensing, active probes, external triggering and so on.

Check the Rohde & Schwarz website for more information on the scope and all its features (**www.rohde-schwarz.com/au/product/rtm3000**).

Conclusion

If you are in the market for a fully-featured scope with a bandwidth up to 1GHz, the Rohde & Schwarz RTM3004 is well worth considering – especially if you're keen to get an instrument that's easy to drive.

For more details, see the Rohde & Schwarz Australia website at **www.rohde-schwarz.com/au/**

For pricing or to order a scope, phone (02) 8874 5100 or email **sales.australia@rohde-schwarz.com** SC

Features

- 10.1-inch 1280 x 800 touchscreen display
- Four analog and 16 optional digital channels
- Bandwidth: 100Mhz (upgradeable to a maximum of 1GHz)
- Sample rate: up to 5Gsamples/s
- Memory depth: 40Mpoints/channel and up to 80Mpoints interleaved
- Wafeform capture rate: 64000/s
- 500µV/div maximum sensitivity at full bandwidth
- 10-bit ADC
- Connections: LAN, USB, Ethernet

SERVICEMAN'S LOG

Why can't I program MY alarm?

Dave Thompson*

Many moons ago, I wrote about an alarm system I was having trouble with at my then residence. I'd experienced intermittent problems with it in the final few months of its almost ten-year lifetime and it had finally given up the ghost, which was a real shame as it had been such a good system.

Items Covered This Month

- Bosch burglar alarm
- Marantz SR870 receiver repair
- Mitsubishi air conditioner

*Dave Thompson runs PC Anytime in Christchurch, NZ.
Website: www.pcanytime.co.nz
Email: dave@pcanytime.co.nz

~MANY MOONS AGO, I WROTE ABOUT AN ALARM SYSTEM I WAS HAVING TROUBLE WITH

It had protected, without fault, a couple of our dwellings with attached workshops and had been disassembled and re-installed several times as we'd moved from place to place in the early days.

The problem with all electronic hardware is that it is usually quickly superseded and this alarm system was no exception.

Of course, the alarm company who'd originally installed it was more than happy to pull it all out and replace it with a shiny new version, with more bells and whistles but apparently that also meant changing all the sensors I'd spent a considerable amount of time and money on.

The sales guy was adamant they were no longer compatible with newer systems, a statement I viewed with great suspicion. I was subsequently vindicated when I learned that all my sensors would have worked with any new panel sourced from this company (and probably dozens of others as well).

However, that deception aside, I was not yet in a position to shell out the amount of money they wanted for a new system, especially as they'd "given" us the old system as part of a deal when we signed up to a monitoring contract with an affiliated security company.

Back then, we got the basic system (which came with three standard PIR sensors and a smoke alarm) if we agreed to a two-year monitoring deal, which was actually a win for both parties. We got a good quality, monitored alarm system and they got a dollar a day from us for a couple of years, guaranteed.

From what the installers said as they put the thing in, they had "sold" a huge number of these package deals and were run off their feet with installation work.

Unfortunately, now many years down the track, that deal – or any others like it – no longer exist, which is why I baulked at the quoted cost of a new system.

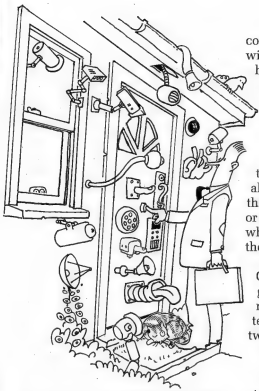
Before making any decisions, I looked at all the alternatives. I wouldn't be much of a serviceman if I neglected to do my due diligence!

The system we'd been using, the Solution 6 + 6, was made by Bosch, a company not known for making junk. So although it was basic and essentially given away as a deal sweetener, it was by no means a bottom-of-the-line system.

We'd also added a whole bunch of extra sensors to the "free" package, as we also wanted to include our garage and workshop, an altogether much larger area than the standard package was designed to cover.

Thus, we ended up with an array of door and window switches, extra smoke alarms and more PIR sensors, with pet-safe versions of these detectors replacing the standard versions that came with the package deal – all at our expense, of course.

Overall, this system was rock-solid. I can only recall one instance of



WE ALSO ADDED A WHOLE BUNCH OF EXTRA SENSORS

it going off with no apparent cause, the dreaded false alarm.

Fortunately, it was in the middle of the day and I was nearby, so no real harm was done. Even though I knew which zone and sensor was responsible, I never did figure out why it went off and as it never happened again, I didn't lose too much sleep over it.

Newer isn't always better

In contrast to this, I have lost count of the number of times the much newer and far more sophisticated digital alarm system (purchased from AliExpress) at our new place has gone off over the last 18 months with no apparent trigger.

Like any electronic device, the more complex it is, the more likely that it will give problems. No doubt there is a law named after some famous academic used to describe this phenomenon, but as I'm not aware of it yet I'll take a punt and call it "the Serviceman's Law".

This new alarm system does have several advantages over that old one though. We now have features such as wired/wireless sensor connections, manual/keypad operation, RFID or key-fob arm/disarm and both GSM and copper-line connectivity for monitoring.

If required, I could use up to 99 sensors with the new system, while I could wire in a maximum of only 12 with the old one (and even then, I'd have to use some jiggery-pokery to achieve that).

Still, that old system was high-spec in its day, and as I said, it hardly missed a beat until a few months before it died.

As I wanted to keep using it at the time, I'd needed to come up with an alternative to total replacement, and that meant finding a new main board, or perhaps a whole new alarm panel, which was a tough ask considering the age of it.

As it turned out, I got very lucky. On a local auction site, I found a guy selling a brand-new panel and a new, spare keypad for my exact system. He'd somehow ended up with two panels and an extra keypad for a job he was doing (I didn't ask) and now, a while after the fact, he was cleaning out his garage and wanted to be rid of it.

I was happy to part with a hundred bucks for the panel and keypad, which was a bargain considering what the alarm company wanted for that new system.

The new panel included the steel mounting box and power supply board. All I had to do was disconnect and remove the old box and then connect and mount the new one using the same screw holes.

It was an easy task; I didn't require any diagrams or circuits as I just swapped out sensor wires and resistors from where they were connected on the old board to the corresponding terminals on the new panel.

The most difficult and time-consuming part of the whole process was programming the new board with all our settings. This process also raised an interesting philosophical issue. The new main board had been pre-programmed by the alarm company who'd imported it using their own unique installer code, which meant that I could not fully program the alarm board as I didn't know the code; the seller didn't know it either.

There are two codes used in this system, both of which have their own levels of access to the system and its various functions. The installer code is used to program all the non-consumer related information into the panel, such as telephone numbers for remote monitoring, different options for the various types of sensors, zone settings and other miscellaneous technical parameters.

Importantly, the alarm cannot be armed or disarmed using the installer code, a necessary safeguard to help prevent rogue installers going around disabling alarm systems.

That said, installers can add "master" codes, which are used to disarm systems, and they usually do so as a service to the customer, mainly because most new alarm owners do not have the desire to go poking into the workings of the alarm system, nor do they want to have to wade through the manual in order to learn how to program in their own codes.

Those who are prepared to read the instructions, or who are concerned about others (namely the installers) knowing their alarm codes are able to create their own master codes, although this is about the only thing they can do without requiring the installer codes as well.

The main problem is that, for obvious reasons, the installer codes are almost never released by the alarm companies.

This raises the philosophical issue I speak of; while it is fair enough for installers to retain those codes if they (or their affiliated monitoring company) have installed a "free" alarm system along with a monitoring deal, I bought and paid for this particular panel outright, so surely I should be privy to any and all codes and keys used in the system.

Not knowing that installer code, severely limits what I can do with it, and this is just not cricket. This would be akin to me putting a BIOS or set-up password on every computer I sold and then charging a fee to anyone who wanted to get into the BIOS to, for example, add another hard disk or alter existing settings.

To any right-thinking person, this is not acceptable, and yet as far as I can tell this is industry practice in the alarm business.

There is a potential "back door" though; the main logic board has a "set default" button on it, which does exactly what you'd think it does, and that is re-set any programmed settings back to their factory defaults, including the installer code and master codes. This action can also be accomplished using certain codes sent to the logic board via any of the alarm keypads.

However, as always, there's a gotcha involved. There is an installer option to protect that setting and this prevents the set default button or keypad codes from being used to default the system settings.

While the service/installer manual specifically advises against using this setting, as it requires the unit to be sent back to an authorised agent for re-programming (or in this case, requires me to pay some guy to come out and do it), this particular company chose to ignore the instruction manual and set that option to on, preventing me from using it to default the settings. Nice one.

I understand there are business and security implications to this, however, any bad guy would have to be pretty clued up in order to go around accessing alarm systems and besides, it would be a pretty obvious clue if the alarm was disabled by someone other than the owner. Either way, in my opinion, setting an installer code and making it non-removable is not warranted, period.

In the end, I had to pay a couple of likely lads to come out and remove that installer code. They didn't want to do it, and certainly wouldn't tell me what the code was – not that it mattered; I neither needed nor wanted to know it, I just wanted it defaulted – but it turned out that they didn't actually know it anyway.

However, I put my case in strong terms that this was now my alarm and as such, they or their colleagues had no right to set any passwords or codes into it that prevented me from accessing any settings within it. After a lot of back and forth and a few phone calls to superiors and other installers, they agreed to default the panel, trying all the codes they knew, including those used both past and present, to default it.

They eventually chanced upon it setting everything to default. Commenting that this code had not been used for many years, they eventually loosened up and showed me around the programming side of things and even demonstrated how to use a programmer board to make things easier, and double-checked the option that prevented the defaults from being set was disabled.

In the end, we recognised we were all servicemen and as such were kindred spirits. They knew I wouldn't be going around busting open alarm systems and were happy to share those few tricks of their trade. I've engaged them several times since to do alarm-related work and it is nice to have a connection to people with those specialist skills.

Well, that's one way to stop it beeping

I bring the subject of this alarm system up because last week the guy who'd been renting our old place (the one with the repaired system installed in it) moved out.

When I went in to check the property out, I found he'd somehow disabled the alarm system; it was completely dead. When this bloke had first moved in, he'd mentioned that the alarm would be a welcome asset as he had some expensive laser-cutting equipment he wanted to set up in my old workshop.

Obviously, something had changed in the meantime, so I got in touch to determine why the alarm was no longer working. He claimed that shortly after he moved in, it started displaying a "mains" error on the keypads and because of this, the system beeped once a minute, which it is designed to do.

Not knowing better, he'd climbed up to where the main alarm panel is located, opened the box and disconnected the mains connections and battery terminals, thus shutting the whole thing down and killing the beep.

If he had called me, I could have told him how to stop that beeping in five seconds with the push of a keypad button. However, he fancied himself a bit of a DIYer and preferred to resolve it himself in his own refreshingly non-technical way.

I empathised though; that beep is annoying. Every keypad has a piezo buzzer, so any warnings are audibly announced, along with flashing zone LEDs, and in this case, the warning would go on either until mains power was restored or the battery went flat (or someone physically unplugged it!).

During the quakes, we lost power a lot, so I am intimately familiar with that particular warning. Still, his response was a little heavy-handed, and as it turns out, there were a few other "command" decisions he'd made that he wasn't entitled to make as a tenant; the alarm is just one example.

The first thing I had to do was dig out the alarm's service manual again. With no power for over a year, I might need to re-program it. I made my way into the roof space and found the panel door wide open and full of new residents.

A quick vacuum cleaned it all out and I could then see he had simply cut the wiring. Again, if he'd called I could have told him where the master switch was at ground level.

None-the-less I reconnected it all, but when I flicked the mains switch on, there was nothing, though when I re-connected the battery leads, I heard a beep and the keypads lit up with fault indicators. At least the battery was holding its charge; fortunately, I'd replaced it not long before we moved out so it was still fairly new.

However, the problem was still no mains power. I broke out my line testing tools and worked backwards from the panel through the system until I discovered that the mains feed to the panel was dead because this guy had wired in an extractor fan for his laser and had inadvertently killed the alarm circuit, which caused the mains fault.

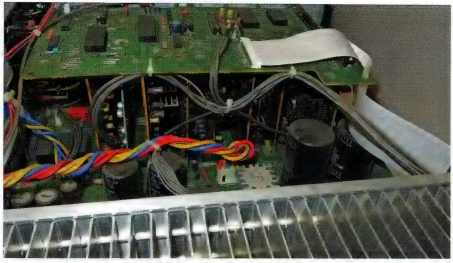
He'd removed and taken the fan away, so I used a junction box to re-con-

Servicing Stories Wanted

Do you have any good servicing stories that you would like to share in The Serviceman column? If so, why not send those stories in to us?

We pay for all contributions published but please note that your material must be original. Send your contribution by email to: editor@siliconchip.com.au

Please be sure to include your full name and address details.



The Marantz receiver is tightly packed with components, making testing difficult.

nect the loose cables and with power restored, the beeping stopped and the fault cleared. All my settings had been saved, but I changed all the codes anyway, just to be safe. Who knows, there may be servicemen around who are not as trustworthy as I am!

Marantz SR870 receiver repair

R. A., of Melbourne, Vic, recently fixed his venerable Marantz SR870 Home Theatre Receiver. It has given nearly 20 years of sterling service and will now likely soldier on for another 20. The fault he discovered was all too common and luckily, easily fixed. Here's his story...

While studying to be an engineer, I worked as a serviceman and have dabbled in servicing ever since. Like all servicemen, my own gear is the last to be fixed. My 19-year-old Marantz SR870 5.1 channel home theatre receiver had been playing up for well over a year.

Every now and then, it would spontaneously power down then usually quickly reset, sometimes repeating the cycle then usually settling down. Recently it played up more frequently and now would sometimes not recover at all for quite some time.

Eventually, I decided to do something about it. My initial thoughts were to suspect a capacitor in the power supply or maybe even a faulty fuse. After removing the receiver from its place in the system (no trivial task and the reason for the procrastination), I pulled the cover off and inspected the power supply board.

Everything looked fine. No bulging capacitors, the fuses looked rock solid and were a quality type. The fault was so intermittent that waiting for it to fail on the test bench was an exercise in frustration. It was clear to me that all mains power was being lost when it did fail, so I did the easy thing and replaced the mains cord, which had some very sharp bends in it where it was clamped in several places.

Back in use, it worked well for about 24 hours – then failed again.

The receiver was packed full of components (as shown by the photo above), had been well built and was in excellent condition, so I was loath to start pulling out components on a search-and-destroy mission. Even measuring voltages was impossible on some of those nested PCBs.

Instead, I looked on the internet for clues but there was little information available. However, I came upon a YouTube clip where an American technician worked on a similar receiver. The interesting thing was that there were lots of comments below the video, none of which related to the video but were asking all sorts of questions regarding receivers and faults.

The small power input PCB from the receiver.

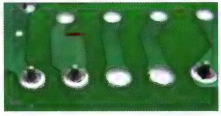
The technician replied to all comments with patience and much insight. So, I took a chance and asked about my SR870. Overnight he replied, saying that there was a common problem due to poor soldering on the power input PCB. In particular, he said to check the soldered joints on the small standby transformer and regulator IC.

I retrieved the unit and opened it up again, then removed the PCB in question (shown in the previous photo).

It was relatively easy to get the PCB out; I just needed to remove the big main transformer to give some wriggle room and also work out how to unclip each small connector. Only two of the five used the same locking tab arrangement.

Using reading glasses with three times magnification, I discovered that at least one soldered pin on the primary of the transformer looked dodgy. So I took macro photos and then re-soldered every transformer pin and every pin on the aforementioned IC and put everything back together.

Cutting to the chase, this completely fixed the fault. Later, looking at the photos on a large monitor, it was obvious that all three of the primary pins of the transformer, along one side, had faulty soldered joints (see the photograph below). All the other joints looked OK.



My theory is that a flawed mechanical design caused this issue. The manufacturing process required the transformer to be first soldered to the PCB, then two long self-tapping screws went through lugs on the transformer, through the PCB, through a standoff, to the chassis.

Tightening these screws forced the transformer into the PCB and thus placed strain on the solder joints.

I was happy to have given the receiver another lease on life. Reflecting on it later, you might think that a receiver that old should be replaced by a newer "better" unit.

In fact, it was already superseded when I bought it new (at a good price) in 1998 as it only had Pro Logic decoding, not Dolby Digital or DTS.

However, it has an analog 6-channel direct input to cater for then-future decoders, so I have used it continuously with a variety of DVD players with 6-channel outputs, plus PVRs and other boxes over the years.

Hence, the amp is future proof, which fits my philosophy of also buying the dumbest TV and using it with an external set-top box (with built-in media server/PVR/Fetch box/etc).

It's much cheaper to replace a box when technology advances than replace the amplifier or large screen. The introduction of H.264 compression is one example where this philosophy pays off.

Also, I reflected on the good electronic design that utilised 1000+ electronic components that still work perfectly 20 years after manufacture, 25+ years after it was designed. Would today's replacement actually be "better"?

Researching possible new replacement units, a popular brand has a 7-channel, 115W/channel (single channel driven rating), and weighs just over 8kg, retailing at about $1000.

The old Marantz weighs 14.4kg, most of it being the power transformer. Rated at 110W/channel (two channels driven), its multi-channel performance would easily eclipse the new unit due to the much beefier power supply.

So I am glad to have given the old Marantz a new lease on life. I also still have the original RC2000 remote control – the "Remote of the Gods" – but that is a story for another time.

Mitsubishi air conditioner repair

J. N., of Mt Maunganui, New Zealand, recently faced a common problem with his home air conditioner; spare parts were becoming so expensive and difficult to get that it looked like it might be cheaper to replace the whole thing than repair one small fault. Luckily, he managed to get it going again anyway...

As a semi-retired electrical/electronics technician, I like to do any servicing or repairs on our home appliances myself. The one time that I decided not to, it ended up with me finishing the task anyway!

About a year ago, we had an extra Mitsubishi heat pump installed in our house, adding to our existing old but faithful Mitsubishi MCFH-A18WV. I usually service the old unit myself but we decided to have both units serviced by the installer of the new unit before winter set in.

They arrived and proceeded to service both units and found that the old MCFH-A18WV would turn off OK but the internal fan kept running.

According to the service engineer, the problem was in the main Electronic Control (EC) PCB and it would have to be replaced. I requested that they give me quote for the supply and installation of this unit.

His estimate was around $300-500 for the part plus labour, which made me flinch! I asked him to please check this out with a firm quotation.

A couple of days later, the company came back with very pleasant news indeed. It appeared that because our old unit was so outdated that there was only one PCB in stock in the whole of New Zealand and the agents were prepared to let us have it for only $32.90 including GST! Well, of course, we agreed.

Several days later, our service engineer turned up and duly replaced the Electronic Control PCB, only to find that now the internal fan motor did not work at all!

After a lot of testing, he now announced that the fan motor had burnt out one of its windings and also that the main EC PCB was probably corrupted and would have to be replaced again!

By this time, I was beginning to think that we should bite the bullet and replace the whole unit. It was agreed to get a further quote from Australia for parts alone, ie, the fan motor and a new EC PCB.

In the meantime, I decided that it would not do any harm for me to investigate myself. I was able to download the circuit diagrams and went about conducting my own tests.

All seemed well until I came to check the fan motor stator windings which involved one main winding and four separate coils, providing different fan speeds.

Sure enough, the main stator winding showed an open circuit on my ohmmeter. This did not make sense until I re-checked a separate circuit diagram which showed in very small detail that this winding was protected by a fuse.

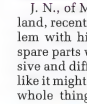
Where was the fuse, as none was in sight? The penny dropped; it was embedded in the windings and was obviously a thermal fuse.

I simply bypassed this fuse by temporarily altering the wiring and the retested the winding to find that it read the required 79-97Ω. At switch-on, the unit operated as it should, so the new EC PCB was not faulty.

True to their word, I received a phone call from the servicing company to inform me that a new fan motor and EC PCB would cost over $1000 plus labour and GST.

I am not sure what they thought when I informed them that the unit was working fine and we would not need the new parts.

Since then, I have removed the fan motor and installed a new thermal fuse as best as I can, to protect the motor, and I am still going to attempt a repair one day on the old EC PCB which had been previously removed. In the meantime, our good old heat pump is still chugging along. SC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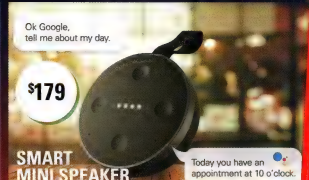

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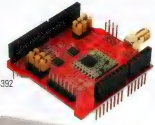

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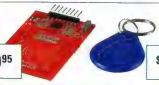

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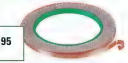

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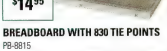

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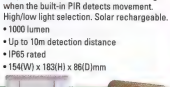

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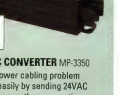

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TECH TALK:

Digital Video Recorder (DVR) Vs. Network Video Recorder (NVR)

READ THE FULL ARTICLE: jaycar.com.au/dvr-nvr

Video surveillance systems have many applications in the home, office, commercial and public venues. Depending on the choice of camera technology you will require either a Digital Video Recorder (DVR) for connecting to analogue cameras, or a Network Video Recorder (NVR) for connecting digital IP cameras. A DVR and NVR essentially provide a central connection, control, storage and streaming of your surveillance video camera network. Most DVR's and all NVR systems provide secured remote access, allowing you to conveniently view your camera footage over the Internet.

Analogue and digital IP cameras offer comparable video quality, IP Cameras offer slightly higher image resolution, and greater flexibility as they can be connected to the NVR unit via wireless, Wi-Fi or only require standard network Ethernet cable connection. Analogue cameras, on the other hand, require special coaxial and power cable connection from each camera to the DVR unit. Planning your surveillance network is very important whether you use a DVR or NVR, you need to ensure there is enough storage capacity to record your video footage over the required surveillance duration say 24 hours, 48 hours, etc., in the case of an NVR you also need to ensure there is enough data network bandwidth to carry the video footage data stream from each camera to the NVR unit, without affecting the rest of your data network.

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- Output: Modified sine wave
- Typical backup time: 31 mins small load

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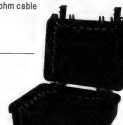

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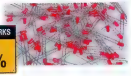

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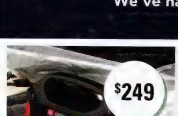

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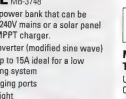

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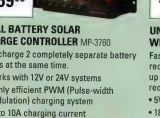

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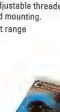

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CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

Temperature and humidity display using a PIC16F88

Back in the February 2017 issue of SILICON CHIP, Jim Rowe wrote an excellent article on the AM2302/DHT22 temperature and relative humidity sensor module (www.siliconchip.com.au/Article/10529).

Not having a Maximite or Arduino but having lots of PIC16F88 microcontrollers, I thought I would design a circuit using one of those to display the temperature and relative humidity on an LCD.

The main difficulty in doing this is the fact that the AM2302/DHT22 does not use a standard communications protocol but rather a custom one so I had to write software for the PIC to receive data from the sensor.

The pin 2 output of the AM2302 is connected to RB0 on IC1. Initially, this port is made an output and the micro then takes this pin low for 1ms.

The port is then made an input and the AM2302 sends out an acknowledgement (positive) pulse of 80µs. IC1 checks the width of this pulse and if it is less than 60µs, it starts the whole process again.

If it is more than 60µs, the pulse width is stored (as a reference) and it then waits for and stores the duration of the next 40 pulses in memory. These encode the humidity, temperature and checksum data.

It then goes through these stored pulse widths to determine if each one represents a logic 1 or a 0. A logic 1 is assigned to any pulse of 60-90µs and a logic 0 for any of 20-40µs.

The relative humidity is calculated from the values of the first 16 bits, the temperature from the next 16 bits and the checksum from the last 8 bits. If the checksum value received matches the checksum of the rest of the data then the relative humidity and temperature are displayed on the LCD.

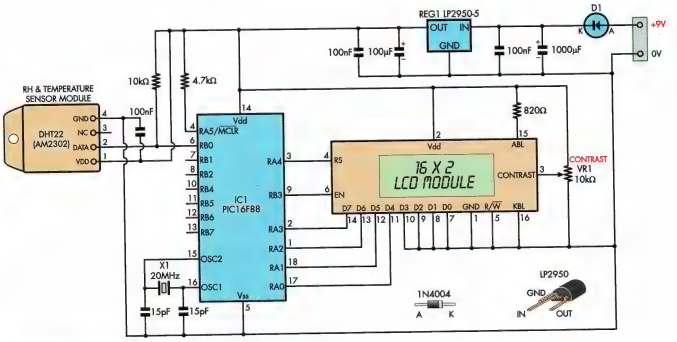
In the unlikely event that interference causes the parity to be incorrect, an asterisk ("*") is displayed before the humidity and temperature to tell you that the reading may be incorrect.

The rest of the circuit is simple. The PIC drives the alphanumeric LCD using the 4-bit parallel bus. It also has a 20MHz crystal connected between pins 15 & 16, with 15pF load capacitors, so that the chip can accurately measure the width of the pulses from the DHT22.

The whole circuit runs from a 9V unregulated supply which could come from a battery or plugpack. The 9V supply is regulated to 5V to suit all the other components by a TO-92 package LP2950-5 linear regulator. 10kΩ potentiometer VR1 enables you to adjust the contrast of the LCD screen.

The software was written using PICBASIC PRO. The commented source code "Temp hum 3.bas" and HEX file "Temp hum 3.hex" can be downloaded from the SILICON CHIP website, free for subscribers. The HEX file can then be flashed to the PIC using a PICkit 3 or similar.

Les Kerr,
Ashby, NSW. ($60)



SC TEMPERATURE & HUMIDITY DISPLAY

Electric Guitar/Violin preamp runs off USB supply

This high-input-impedance preamp has been designed to run at 5V to provide the convenience of operating from a USB supply. That means you can power it from the USB port of a computer, a USB charger or power bank. It only draws a few milliamps.

You need to have a high input impedance, usually at least 1MΩ, for a piezo-electric instrument pickup or else the low end frequency response can suffer.

One of the challenges of designing such a preamp to run off 5V is that the instrument can produce a fairly high output voltage which would exceed the 5V rails. So this preamp includes a selectable input divider to reduce the instrument voltage to a suitable range for the preamp. The signal level can then be boosted again before being fed to the output.

The circuit is designed around an MCP6024 quad rail-to-rail op amp. This op amp runs from a 2.7-5V supply, it has a gain bandwidth product of 10MHz, a noise figure of 8.7nV/√Hz, total harmonic distortion below 0.001% and it is unity gain stable. It's also quite reasonably priced.

It has CMOS inputs, so can be used in circuits with a high input impedance without a high DC bias voltage.

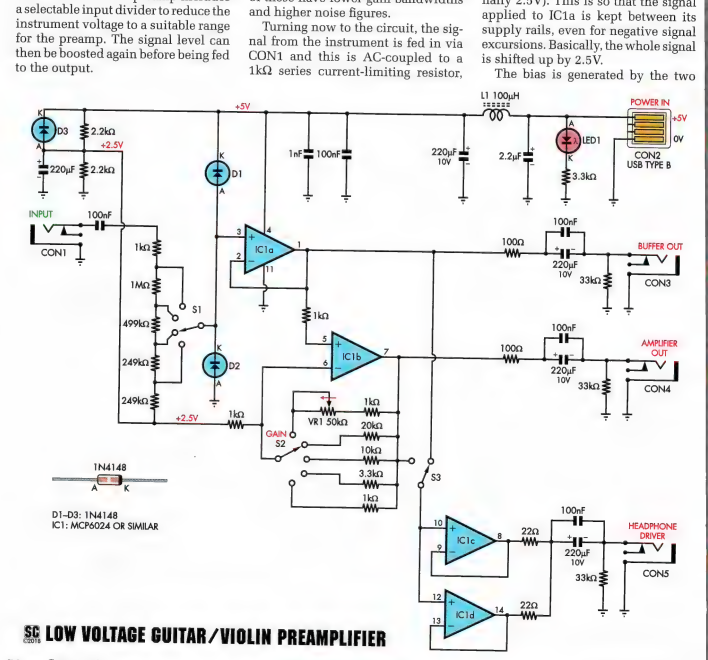
There are various other similar op amps which are suitable but they are generally not as good. These include the MCP604, MCP6284, MCP6074, LMV324, LMV774 and LMV824 but all of these have lower gain bandwidths and higher noise figures.

Turning now to the circuit, the signal from the instrument is fed in via CON1 and this is AC-coupled to a 1kΩ series current-limiting resistor, followed by a resistive divider comprising four resistors. These resistors total just under 2MΩ, defining the input impedance.

Rotary switch S1 allows you to feed the unattenuated signal to input pin 3 of IC1a, or one of the taps on the resistive divider network which give attenuation factors of 2, 4 or 8. Diodes D1 and D2 ensure the signal fed to IC1a does not go very far below 0V or above 5V. IC1a is configured as a unity-gain buffer.

Note that the bottom end of the divider network does not go to ground, but instead to a half supply rail (nominally 2.5V). This is so that the signal applied to IC1a is kept between its supply rails, even for negative signal excursions. Basically, the whole signal is shifted up by 2.5V.

The bias is generated by the two



LOW VOLTAGE GUITAR/VIOLIN PREAMPLIFIER

2.2kΩ resistors across the 5V rail, shown at upper left, with a 220µF filter capacitor to prevent supply ripple and noise from getting into the signal path.

Diode D3 discharges this capacitor quickly when power is removed so that it does not discharge into one of the op amp inputs via the op amp's internal clamp diode.

The buffered signal from IC1a is fed to CON3 via a 100Ω series resistor and 220µF capacitor. The resistor isolates any capacitance at the output from op amp IC1a, so that it won't oscillate, while the capacitor blocks the 2.5V DC bias voltage.

The output end of this capacitor is biased to 0V DC (ground) potential via a 33kΩ resistor. A 100nF capacitor across the 220µF capacitor keeps the output impedance low at higher frequencies.

The buffered signal is also fed to the non-inverting input (pin 5) of IC1b via a 1kΩ resistor.

This resistor is inserted to keep the input impedance seen by the op amp's two inputs similar, avoiding excessive thermal drift and improving common mode rejection. IC1b is configured as a gain stage with selectable resistors in the feedback network so that S2 can select one of five different gain settings.

With S5 in the upper position, the gain can be varied between two times and 52 times using potentiometer VR1. The other four positions give fixed gains of two times, 4.3 times, 11 times or 21 times.

This allows you to use the preamp with different instruments and quickly switch to the required gain setting for each one. The output of IC1b is fed to CON4 via the same coupling arrangement as CON3, described above.

S3 allows you to select the output of either IC1a (buffered only) or IC1b (with gain) to feed to the mono headphone driver, which is built around IC1c and IC1d.

These are configured as unity-gain buffers and connected in parallel, with 22Ω resistors from the outputs to prevent them fighting each other due to slightly different DC offsets.

This arrangement increases the output current capability and allows the op amps to drive a lower load impedance.

The common output is coupled to the headphone(s) via another 220µF/100nF capacitor pair and also biased to ground by a 33kΩ resistor. With 30Ω headphones (only one side driven), you can expect a frequency response down to about $1 \div (2\pi \times 30\Omega \times 220\mu F) = 24Hz$ (the -3dB point).

The power supply is simple; around 1mA is fed through power indicator LED1 and a 2.2µF capacitor stabilises the supply voltage (note: the USB specification allows limited capacitance across the USB socket, to prevent high current flow when plugging the device in).

An LC low-pass filter comprising 100µH inductor and 220µF capacitor filters out the worst of the high-frequency noise which may be present on the output of USB chargers. 100nF and 1nF parallel bypass capacitors are provided for quad op amp IC1; the lower-value capacitor will typically be more effective at higher frequencies.

Petre Petrov,
Sofia, Bulgaria. ($65)

Recycling old hard disk spindle motors

Useful motors can be salvaged from defunct hard drives and they can be used for many projects that require a low-power motor, especially one which can spin at a high rate.

Typical hard disk motors are designed to spin at 5400, 5900 or 7200 RPM although some run as fast as 15,000 RPM.

The only difficulty in re-using them is the electronics required to drive them. These are three-phase motors with four wires but they can be driven as a standard Brushless Direct Current (BLDC) motor by ignoring the centre connection.

A simple way to drive these motors is with the MTD6501G single chip BLDC motor driver from Microchip. The chip is only available in a surface mount (SOIC-8) package but this can easily be soldered to an SOIC-8 to DIL-8 adaptor board (eg, Silicon Chip Online Shop Cat SC3195 or SC3196) so it can be used on a breadboard or prototyping board.

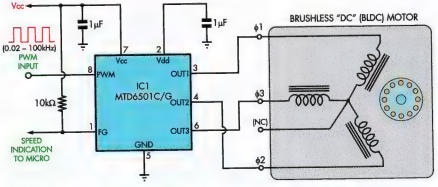
The SC3196 adaptor has a thermal pad which can be soldered to the underside of the IC for better heat dissipation.

You can use hot air reflow with solder paste to make the solder joint under the IC but if you don't have the equipment, you can simply smear some flux paste on both sides of the PCB before soldering the IC pins, then flow solder through the central via from the underside of the board.

The circuit diagram shows the required connections. Speed control can be provided by a pulse width modulated (PWM) signal from virtually any microcontroller including Arduino, Micromite, Raspberry Pi etc.

Set the duty cycle to 50% and vary the frequency to control the motor speed. Connecting the PWM input directly to V_{CC} will provide maximum speed.

For most motors, a V_{CC} of 3.3V or 5V is suitable, although this probably won't allow the motor to run at full



SC 3-PHASE BRUSHLESS MOTOR SPEED CONTROL

Simple Valve Radio Battery Eliminator

This circuit is similar in concept to the Mains Power Supply for Battery Valve Radio Sets (August 2017; siliconchip.com.au/Article/10751).

This circuit is considerably simpler, easier to build, cheaper and safer (since its mains transformer is a plugpack), however, it doesn't provide quite as many supply options.

I decided to design this because I recently acquired a battery valve radio from the 1950s. It's a Philips model with four valves in a standard superhet configuration. It runs from batteries, without a mains supply option. Like many battery valve radios, it needs 1.5V DC for the filaments and 90V for the HT supply.

Since the old-style A/B batteries are no longer available, I could have used a D cell for the filaments and ten 9V batteries in series to achieve 90V. But that would not be very satisfactory from my point of view. And anyway, I already had all the parts to build this supply in my collection.

As shown in the circuit diagram, I used an AC plugpack with a 9V, 1A output. This is fed to a 7VA PCB-mount transformer with a 230V primary and two 12V secondaries. By feeding the 9VAC into the two 12V windings in series, this gives 92VAC on the 230V winding with no load.

This is higher than the turns ratio would suggest and is due to the fact that with no load, the 9VAC output of the plugpack is actually about 11.8VAC.

Bridge rectifier BR2 followed by a 33µF, 150V electrolytic capacitor converts this 92VAC to 123V DC, again, with no load. 33µF is quite adequate for filtering.

I used a 350V capacitor since I had it in my parts bin. A 150kΩ resistor across the 33µF capacitor discharges it quickly at switch-off and dissipates under 100mW.

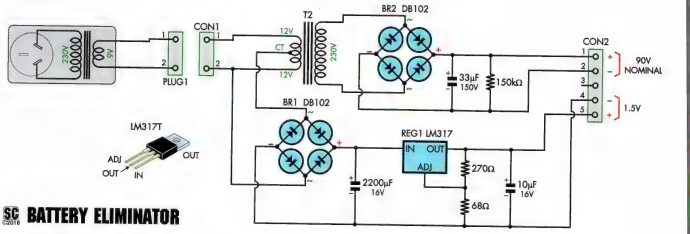
To obtain the 1.5V DC for the filament supply, I wired bridge rectifier BR1 across just one 12V winding, with a 2200µF capacitor for filtering.

Hence, I am using the input side of T2 as an auto-transformer to lower the AC voltage. This gives about 6.2V DC to feed to the LM317 adjustable regulator, REG1.

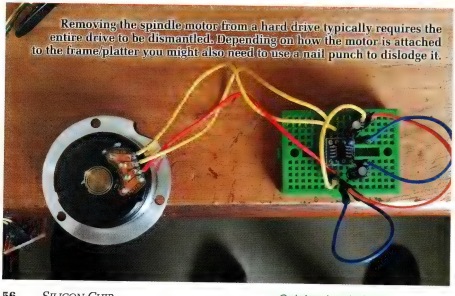
The two resistors between the output and adjust pins of REG1 and ground actually give me 1.56V DC.

I designed it this way because I discovered that the ON/OFF switch on my radio has a rather high resistance and no matter how much I cleaned it, there was about a 0.1V drop across it. But any set that's designed for 1.5V should run happily at 1.56V.

The transformer isolates the low



SC 2017/8 **BATTERY ELIMINATOR**



Removing the spindle motor from a hard drive typically requires the entire drive to be dismantled. Depending on how the motor is attached to the frame/platter you might also need to use a nail punch to dislodge it.

speed; the hard disk controller would normally use a 12V supply and probably a different control method.

There are numerous styles of hard disk motor but most are similar to the one shown in the photograph directly to the left.

In order to identify the common connection, measure the coil resistance between each connection with an ohmmeter (eg, DMM set to ohms).

One pin will show a lower resistance reading to the other three. This is the common connection since the reading is across only a single coil. A typical resistance reading is on the order of 3-4 ohms.

Dennis Smith,
Strahan, Tas. ($60)

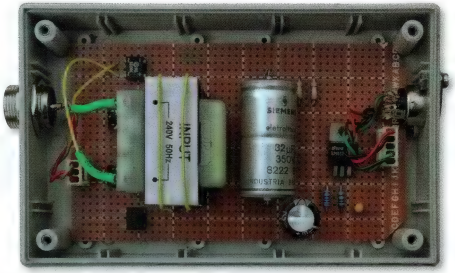
voltage and high voltage outputs (ie, they can float relative to each other) so there should be no problems with whatever biasing scheme is used in the radio.

As mentioned earlier, the no-load HT output is higher than the required 90V but once connected to my set, it drops to about 86V with a ripple of 1.5V peak-to-peak.

Given that the plugpack output winding has a resistance of 450Ω and T2's windings are around 570Ω each, voltage regulation is not great. But in this case, that works in my favour.

There are many variations possible with this kind of configuration. You can change the HT voltage somewhat by substituting a different transformer for T2. For example, using a 15-0-15 transformer would give you a lower HT while a 9-0-9 would give a higher HT.

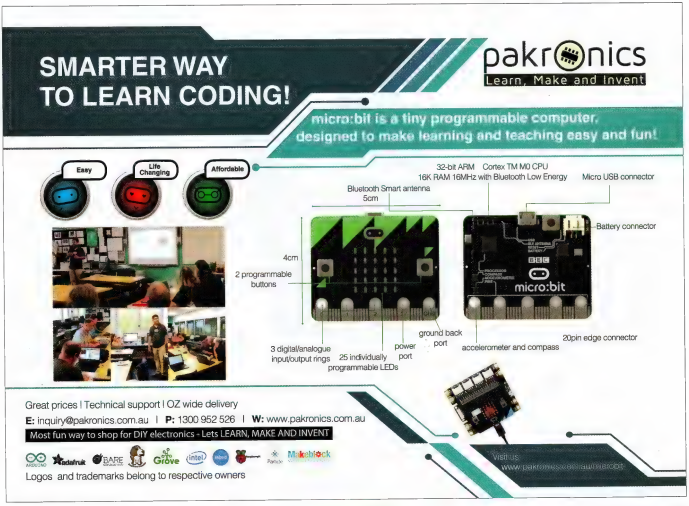
A photograph of my prototype is shown above. Despite the fact there is no mains wiring inside the box, don't be complacent, 100V+ can still be dangerous. Use heatshrink to insulate all the wiring associated with the HT output.



The circuit can be built on a breadboard due to how few components there are. The only reason the transformer is mounted sideways is to fit into the case.

You will notice that I've mounted the transformer sideways. This is simply because, if mounted in the normal orientation, it's too tall to fit into the case that I happened to have (and which is otherwise a good fit). A couple of wire straps and the lid hold it in position.

Charles Kosina,
Mooroolbark, Vic. ($60)



How to use Internet Time with GPS clocks

The "Clayton's" GPS Time Source*

We've produced a number of GPS-based clocks over the last few years but they can be problematic if you can't get a GPS signal – deep inside a building, for example. But how about this for a clever alternative: program a cheap WiFi Module to act as a time reference, kept accuracy via the internet! It pretends to be a GPS unit, so any GPS clock can use it!

By Tim Blythman

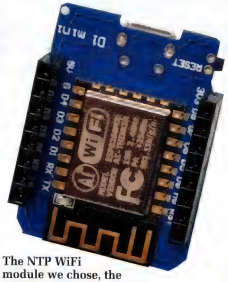
Clock projects that depend on a GPS source as the time reference can be relied on as being highly accurate – after all, the time code in the GPS signal is derived from an atomic clock.

The most recent GPS-synchronised clocks we've published are the Analog Clock Driver (February 2017; siliconchip.com.au/Article/10527 and the High Visibility 6-Digit LED GPS Clock (December 2015 & January 2016; siliconchip.com.au/Series/294).

And in the case of the High Visibility 6-Digit LED GPS Clock, it requires no manual adjustments for daylight saving or time zones as it can determine these adjustments based on location data from that same GPS module.

Unfortunately, all GPS-based clocks are subject to one caveat: they won't work well without having a clear "view" of the sky, so that they can pick up the signals from multiple GPS satellites. While GPS signals can usually be picked up indoors, whether you will get them at a given location depends on the construction of the building – and even the weather.

But many readers will already have a WiFi network at home and that gives an alternative source of time that's almost as accurate (far more accurate than you're ever likely to need!). So why not take advantage of it?



The NTP WiFi module we chose, the ESP8266 WeMos D1 Mini Module (available from Jaycar, Cat XC-3852).

This project takes a cheap and readily available ESP8266 WiFi/ARM processor module and uses it to fetch accurate time readings from the internet and pass it through to the clock.

The beauty of this system is that it presents this time reading as if it's coming from a GPS module, so you don't have to make any changes to the clock hardware or software. You could build any of our GPS clocks and with just a small amount of extra effort, get them to run off Network Time Protocol (NTP) time via your existing WiFi network. It should even work with commercial, pre-built GPS clocks.

In fact, this concept can be used with any device that uses a GPS module to get a time signal. It doesn't need to be a clock. But keep in mind that it may not be accurate enough to use as part of a time reference system.

How it works

As already noted, we're using an ESP8266 module which is available pre-assembled, already having an onboard WiFi transceiver. We program it using the Arduino IDE. IDE stands for Integrated Development Environment, which means that it lets you write code for an Arduino, then compile it and upload it to the board.

And note this point; while we are using the Arduino IDE, we are not using an Arduino Uno or related Arduino board!

The software we have developed fetches the current time and date from an NTP server via the internet, then it uses this timestamp in combination with its internal clock to generate a stream of GPS-compatible (NMEA encoded) data, including time signals.

It is possible to estimate your location based on your internet IP address, so our software does just that, translating the IP into a latitude/longitude pair using an online

***The time source you have when you don't have a GPS time source!**

service. So if you are using this module with the High Visibility 6-Digit LED GPS Clock, it can use these coordinates to calculate the correct time zone and daylight saving rules, and it will display the correct local time.

While we've found that the estimated position can sometimes be a few dozen kilometres out, in 99.99% of cases, this will still be in the same time zone, so the time displayed will still be correct.

But if you are using a proxy or VPN, this information may be inaccurate, as the IP service may return coordinates based on your proxy location. But for most home WiFi set-ups, this should not be a problem.

NMEA GPS data

NMEA stands for National Marine Electronics Association; NMEA 0183 is a specification for communication between marine electronics systems, including GPS receivers. Pretty much all GPS receivers produce serial data in this format, which is why we've designed our unit to use this same standard.

We've described the NMEA 0183 standard in detail in the past and we will give some examples below. But for now, you just need to understand that the data is sent over an RS-232 (or similar) serial link, in ASCII text format, with each distinct line being considered a "sentence".

Each sentence is prefixed with a code which indicates what data is contained within. So units receiving this data can skip any sentences with codes that they don't understand. Each sentence contains a series of values separated by commas and terminated with a checksum, so that data which is corrupted during transmission can be ignored.

Since the information from a GPS receiver is simply serial ASCII data, it's easy for a microcontroller to mimic. A GPS receiver will usually transmit around 3-10 sentences, sent once per second. But for our clock projects, only two are important.

These are the RMC (minimum recommended GPS) and GSA (fix validity and active satellites) sentences. RMC contains the GMT/UTC time, date, latitude, longitude, speed, course and magnetic variation data. GSA indicates whether the unit has obtained a GPS fix and a partial list of the satellite Ids used to obtain that fix. See Fig.1 for an example. This was taken from a real GPS receiver.

Without an actual GPS receiver, the latitude, longitude and satellite status will have to be fabricated or estimated; the only information which absolutely needs to be correct is the time and date.

We've also written the software to produce a "dummy" status sentence to show some information about the status of the WiFi connection. Since this is a sentence type that the clocks are not programmed to interpret, they will ignore it. But you could monitor the output of the serial port using a PC as a debugging aid.

```
$GPRMC,013115.000,A,3345.6276,S,15116.8171,E,0.00,157.
35,140218,,,A*76
$GPGSA,A,3,05,31,25,29,02,,,,,,,,2.22,2.02,0.92*02
```

Fig.1: an example of typical RMC and GSA sentences from a real GPS receiver. The RMC sentence provides basic fix data such as latitude, longitude, speed, heading, and most importantly, date and time. In this case, the UTC time is 1:31:15am and the date is 14/02/2018.

What is a Clayton's GPS Time Source?

Some readers (particularly younger ones) may not understand the reference to "Clayton's" – arguably, one of the most famous tag lines to come out of Australian advertising (OK, that and "NOT HAPPY, JAN!").

Back in the 1970s and 80s, there was a non-alcoholic drink called "Clayton's" which was advertised as "the drink you have when you're not having a drink". They, of course, meant alcohol.

Very quickly, the phrase entered the Aussie vernacular; it meant the (*fill in blank*) you had when you're not having (or possessing, or owning, or using etc etc etc!) a (*fill in blank*).

Our "Clayton's" GPS time source is therefore the time source you have when you don't have access to GPS – whether that's because you don't have one (!) or because it doesn't have the clear view of the (northern in Australia) sky and so cannot receive the valid GPS signal.

Network Time Protocol

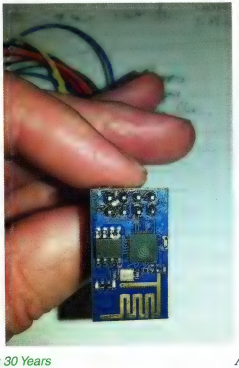
NTP is one of the oldest internet protocols still in use. It's used by pretty much every computer and smartphone, to keep their clocks accurate.

NTP, designed to be simple and fast so that the overhead of checking and adjusting the time is minimised, is well suited to implementation on a small device like an ESP8266 module. It's also designed to compensate for networks delays.

Ultimately, NTP time comes from a source which typically has a caesium atomic clock. From there, the time is distributed to other nearby servers. Our unit will most likely be getting its data via a path that is three or more levels (or "strata") removed from the atomic clock.

In other words, we're synchronising our time to servers which synchronise their time to other servers which synchronise their time to other servers which have atomic clocks attached. Whew!

But you can still expect the resulting time to be accurate within about 10ms. Given that we are transmitting this



Here's an alternative ESP8266 module, the ESP-01 (available from the Silicon Chip Online Store, Cat SC3982). It's smaller but it's not quite as easy to program *in situ*. We have an article describing this module in detail on page 76 of this issue.

data to a clock which will be only be displaying to the nearest second, that should be accurate enough.

To determine the time using NTP, the unit sends out a number of packets over the internet to NTP servers and uses its internal clock to keep track of when each packet is sent and when a reply is received. The response also includes the time (according to the server) when our query was received and when the response was sent. The packets are sent using the low-overhead User Datagram Protocol (UDP).

Using this information, we can determine the round-trip time, ie, the time it takes for our query to get to the server plus the time it takes to get the response. Normally, the route taken by both packets will be similar and so the delay will be similar.

By subtracting the time that the server spent processing our request from the round trip time and dividing by two, we can get a pretty good idea of how long the response took to get to us. We can then add that delay time to the accurate time we receive from the server and that should be close to the exact time when the response was received.

Since we query a number of servers, if a majority of the times determined from the responses are within a few milliseconds of each other, we can be fairly sure that we have a good determination of the time and we can average those results and use that as the correct time.

Features & specifications:

- Uses low-cost ESP8266 WiFi module
- Comparable in size to a GPS module
- Little or no assembly required
- Generates standard GPS NMEA data including time, date, position and signal validity
- Also produces 1PPS pulses (D1 version only)
- Automatically fetches NTP time from internet servers
- Provides approximate location, for clocks with location-based time zone support
- Adjustable baud rate
- Configured via serial port
- Produces dummy status sentences, for debugging
- Power supply: ~70mA at 3.0-5.5V

Keeping track of time

The NTP-based GPS Time Source uses its internal oscillator and timer to keep track of time in the short-term, so it does not need to constantly re-query the servers to determine the time.

This oscillator's frequency may not be exactly right and it could vary with temperature and other factors but since we synchronise it frequently using NTP, it should never drift very far.

In fact, by looking at how it's drifting each time we get a time update via NTP, we can account for and cancel out some of this drift.

That's important since we use this oscillator to determine the one-second intervals on which to send the NMEA data and this gives the clock its seconds "tick". If that was inconsistent or worse, glitched (eg, giving two pulses in short order), you would probably notice.

By default, we perform an NTP update at hourly intervals. The oscillator in the ESP8266 micro is typically accurate to within about ±0.001%. That means that, uncorrected, it will drift by up to 42ms each hour. That's hardly noticeable and the corrected drift is likely to be well within 10ms. You aren't going to notice a 10ms "jump" when the time is updated from NTP.

One thing we haven't mentioned yet is that there are

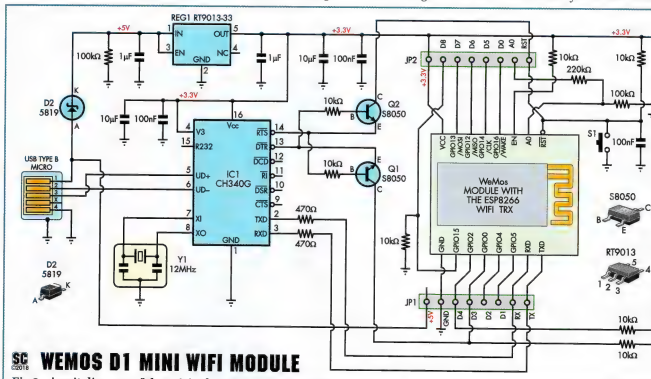


Fig.2: circuit diagram of the original WeMos D1 mini, which has now been cloned and is widely available. It's based on an ESP8266 WiFi module with onboard processor but contains extra circuitry to make it easier to program and use.

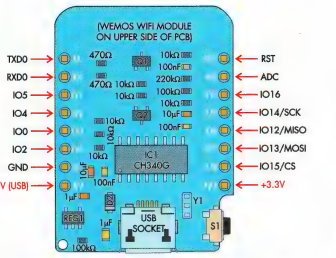


Fig.3: there are several different versions of the D1 Mini board but they are all suitable for this project and have the same pin-out, as shown here. The one we used (a common clone) looks like this but there may be slight variation in the components on the board.

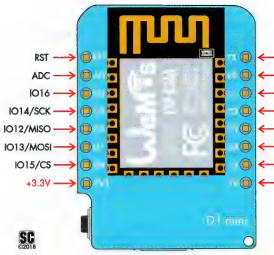


Fig.4: the only part mounted on the the top side of the D1 Mini module is the ESP8266 sub-module, which contains the IC itself plus a few passive components inside a metal shield can. This is the side normally visible when the module is plugged into another board.

actually two different hardware units which you can use for this project. One is smaller and cheaper (ESP-01) but only has eight pins. The slightly larger module (D1 Mini) has more pins and this allows us to also provide a 1PPS (one pulse per second) output, for clocks which require it. See Figs.2, 3 & 4 for details of the D1 Mini.

If available, the 1PPS output is generated from the same oscillator and is driven high briefly at the same time that we start to transmit the NMEA data. We'll get back to discussing the two different hardware modules later.

NTP always gives UTC or Universal Coordinated Time. This is the modern, more accurate version of Greenwich Mean Time, which differs from GPS time by (currently) 18 seconds due to the fact that the GPS satellites are not adjusted for leap seconds when they occur.

However, the GPS data stream does include information about how many leap seconds have occurred, so this can be corrected for.

Most GPS receivers are able to use this information and so give the correct UTC time, but some receivers don't apply the leap second change at the right time. This means that using NTP may actually be more accurate than some GPS receivers.

ESP8266 module

The small size of the ESP8266 module means that it can function as a direct drop-in replacement for many GPS modules.

There are quite a few different ESP8266-based modules available. Our preference is for the WeMos D1 Mini, which includes an onboard USB/serial converter to simplify programming, as well as a 5V regulator, allowing it to be used with both 5V and 3.3V power supplies.

Other modules like the slightly smaller ESP-01 can also be used, but you will need a USB-serial converter to program it and pull-up resistors are also required to get it to operate in the correct mode. We'll show you how to use either module for this project.

The features of the module that we are using are the WiFi connectivity, serial port and also the onboard LED to report some status information. While the small PCB antenna on this module doesn't have a long range, it's expected that it will be used indoors (where GPS isn't available) and probably not too far from a router.

Circuit diagram

The circuit diagram for the ESP8266 WeMos D1 Mini module (available from Jaycar, Cat XC-3852) is shown in Fig.2 and its pinout is shown in Figs.3 & 4. Since this is a pre-built module which does pretty much everything we need it to do, there's no additional circuitry required. We simply feed power into the GND and 3V3 pins and the emulated GPS serial data appears at the TX pin.

If your clock supplies 5V to the GPS module then you can feed this into the 5V pin instead. The onboard regulator then derives the 3.3V supply which powers the module. Regardless, the serial data output will have a 3.3V swing but this is true of most GPS modules (even if they run off 5V) so the clock should not have any problem with this (5V micros can normally accept 3.3V logic levels at their digital inputs).

You can also use the smaller ESP-01 Module (available from Altronics, Cat Z6360) but it cannot easily be programmed as-is. You will need a breadboard, some jumper wires and a few resistors so that you can program it. You will also need to add some components to the board before mounting it in the clock, so that it will operate normally.

The ESP-01 also does not include a 3.3V regulator, so the host circuit will have to supply it with 3.3V or thereabouts (3.0-3.6V is acceptable).

Programming it

Regardless of which module you're using, you need to install the Arduino IDE and the ESP8266 processor add-on so that you can upload the code to it. If you haven't already done this for a previous project, use the following steps – and if you do already have this software installed, check to make sure you have the latest version.

First, install the most recent version of the Arduino IDE onto your PC, if you don't already have it. This can be

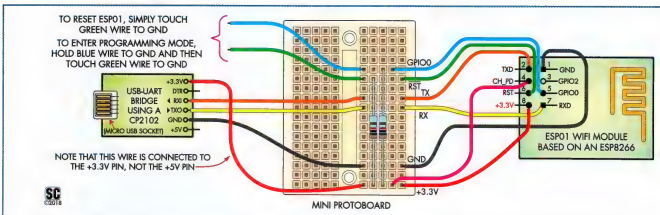


Fig.5: this is how the ESP-01 module is connected for programming. Note the two loose wire "ends", which are used to put the module into programming mode.

downloaded for free from www.arduino.cc/en/Main/Software

Next, install the ESP8266 board files. This is also a free download but it's quite large and will take a while. To do this, open up preferences in the Arduino IDE and under "Arduino Board Manager URLs", enter: http://arduino.esp8266.com/stable/package_esp8266com_index.json (as shown in Fig.6).

Hit OK, then go to Tools → Boards → Board Manager, type in "esp8266" in the search box, click on the entry which appears below and then click on the "Install" button (see Fig.7). This will result in around 160MB of compilers and associated files being downloaded and installed on your computer.

There are two main build options, so we'll run through the easier option first. This is using the D1 Mini module. Go to Tools → Board menu and select the "WeMos D1 R2 & mini" entry. There are no additional libraries to install, as the basic WiFi feature libraries are installed with the ESP8266 processor add-on.

Using a micro-USB cable, plug the D1 Mini module into your PC. Check the ports under Tools → Ports to see that the driver is installed and select the port. If it is not installed, the driver can be downloaded from https://wiki.wemos.cc/downloads

Open the .ino sketch file (downloaded in a ZIP from the SILICON CHIP website) and select Sketch → Upload. If everything completes successfully, you can jump ahead to the Setup section.

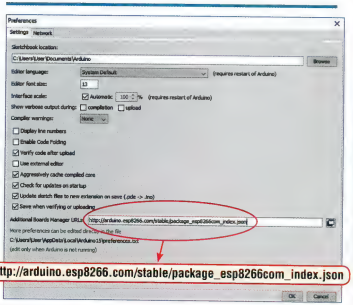


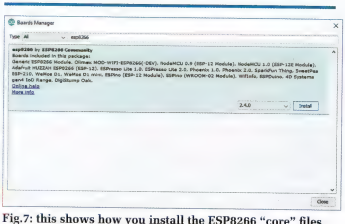
Fig.6: before you can install the ESP8266 Board file, you need to tell the Arduino IDE where to find it. You do that in the Preferences dialog, as shown here.

Using the ESP-01 module

The ESP-01 module is less than half the size of the D1 Mini, which means it can't fit a lot of the nice features of the larger board (such as the onboard USB/serial converter). Still, it isn't too difficult to build a rig for programming this tiny module. You will need a separate USB/serial converter with a 3.3V supply output, as the ESP-01 will not like 5V! We have a suitable device in our SILICON CHIP Online Shop (Cat SC3437). See Fig.5 for the connection diagram.

Connect one male/female jumper lead to each of the ESP-01's pins except for GPIO2 and run the other end to one edge of the breadboard. We used red for VCC, black for GND, orange for TX, yellow for RX, green for RST, blue for GPIO0 and mauve for CH_PD ("Power down"). The mauve lead for CH_PD can connect to the same row as V_{CC}, as CH_PD needs to be pulled up to Vxx for the module to do anything.

Connect another four male/female jumper leads to the


Boards Manager
Type: All
esp8266
esp8266 by ESP8266 Community
Boards included in this package:
Generic ESP8266 Module, Olimex MOD-WIFI-ESP8266(-DEV), NodeMCU 0.9 (ESP-12 Module), NodeMCU 1.0 (ESP-12E Module), SparkFun ESP8266 Thing, Sweet Pea ESP-210, WeMos D1, WeMos D1 mini, ESPino (ESP-12 Module), WiFinfo, Schirmilabs Eduino WiFi, Invent One, LOLIN (WEMOS) D1 R2 & mini, ESPino (ESP-12 Module), WiFinfo, Schirmilabs Eduino WiFi, Invent One, LOLIN (WEMOS) D1 R2 & mini, LOLIN (WEMOS) D1 mini, LOLIN (WEMOS) D1 mini Pro, LOLIN (WEMOS) D1 mini Lite, LOLIN (WEMOS) D1 R1, ESPino (ESP-12 Module), WiFinfo, Schirmilabs Eduino WiFi, Invent One, Digistump Oak, Huzzah (ESP-12 Module), Espresso Lite 1.0, ESPresso Lite 2.0, Phoenix 1.0, Phoenix 2.0, SparkFun Thing, SweetPea ESP-210, WeMos D1, WeMos D1 mini, ESPino (ESP-12 Module), WiFinfo, Schirmilabs Eduino WiFi, Invent One, LOLIN (WEMOS) D1 R2 & mini, ESPino (ESP-12 Module), WiFinfo, Schirmilabs Eduino WiFi, Invent One, Digistump Oak, Huzzah (ESP-12 Module), Espresso Lite 1.0, ESPresso Lite 2.0, Phoenix 1.0, Phoenix 2.0, SparkFun Thing, SweetPea ESP-210, WeMos D1, WeMos D1

USB-serial converter and then connect these to the ESP-01 via the breadboard as follows: red lead to 3.3V, black to GND, orange (from TX on the ESP-01) to RXD on the USB/serial converter, and similarly, yellow (from RX on the ESP-01) to TXD on the USB/serial converter.

The ESP-01 module needs some pull-up resistors for correct operation, so connect a 10kΩ resistor from the V_{CC} row to the RST row (between the green and red jumper leads), and another 10kΩ resistor from the V_{CC} row to the GPIO0 row (between red and blue jumper leads). See Fig.5 for details.

Finally, using male-to-male jumpers, add flying leads to the RST and GPIO0 rows (green and blue). These are now our reset and programming jumpers and we plug them into the GND row to activate them. If you prefer, you could even fit some tactile pushbuttons to the breadboard if you are going to be using this setup more than once.

To reset the ESP-01, touch the green lead to GND. To enter UART upload (programming) mode, hold the blue wire against GND, then briefly touch the green wire to GND, then release the blue wire. You can even touch the green wire to the blue wire (while it is against GND) to ensure everything happens in the right sequence.

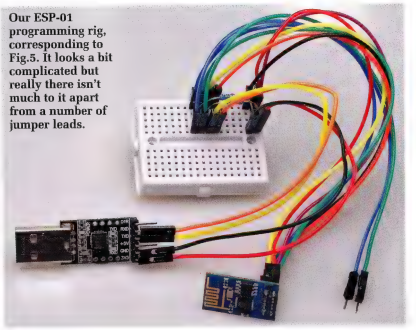
Another trick you could use if you want to make the set-up more permanent is to (carefully!) glue the sockets that are plugged into the ESP-01 together to form a single large socket which can be removed as one piece from the ESP-01. If you are using a cyanoacrylate type adhesive (Super Glue), gently separate the sockets to allow the glue to penetrate, apply a small amount away from the ESP-01, then firmly squeeze them together until the glue takes.

Now, having built our programming rig, we can upload the code to the ESP-01.

Click Sketch → Upload in the IDE and while the sketch is compiling, touch GND to the blue wire, then green and then release green and release blue. The ESP-01 will stay in programming mode until it is reset or a sketch is successfully uploaded, in which case it will run the uploaded sketch.

Any errors will appear in the bottom pane of the Arduino IDE window. If you get errors like "error: espcomm_upload_mem failed", this is because the computer cannot send data to the ESP-01. In this case, try the blue/green sequence again. Usually, the blue LED on the module will blink on and off in "run" mode, but will only briefly flicker once in programming mode, so if the LED is blinking, you may not be in programming mode.

We've found that uploading to the ESP8266-based devices is sometimes less reliable than other devices, so it may simply be a case of trying a few times.



Our ESP-01 programming rig, corresponding to Fig.5. It looks a bit complicated but really there isn't much to it apart from a number of jumper leads.

Set-up

With the sketch completely uploaded to the device, open the Serial Monitor at 9600 baud (you can do this via the Tools menu or, in Windows, the key combination CTRL+SHIFT+M). The program will transmit its current baud rate at 9600 baud before running, so if you see a different number or garbage output in the Serial Monitor, check the displayed baud rate and use that instead.

Within a few seconds, there should be a stream of data on the screen, similar to Fig.8. The lines beginning with "$GPRMC" and "$GPGSA" are our emulated GPS (NMEA) data, while the "$ESP82" lines are debugging information so that we can follow what our NTP-based GPS Time Source is doing.

```
$GPRMC,000002.000,V,3351.000,S,15112.000,E,0.00,000.00,200718,,,*29
$GPGGA,000002.000,3351.000,S,15112.000,E,0,04,1.0,0.0,M,0.0,M,,*75
$GPGSA,A,1,,,,,,,,,,,,,1.00,1.00,1.00,*2D
$ESP82,06,000.000.000.000,0,0,0*78
$GPRMC,215729.688,A,3352.000,S,15110.000,E,0.00,000.00,210218,,,*35
$GPGGA,215729.688,3352.000,S,15110.000,E,8,04,1.0,0.0,M,0.0,M,,*72
$GPGSA,A,3,,,,,,,,,,,,,1.00,1.00,1.00,*2F
$ESP82,03,192.168.043.252,1,1,90348198*4C
```

Time IP Address Latitude Longitude Date

Fig.8: sample output from the completed NTP/GPS Adaptor unit. The GPRMC, GPGGA and GPGSA sentences mimic those produced by a GPS receiver (hence the GP prefixes) while the ESP82 sentence contains our debugging data. You can see that the unit acquired a WiFi IP address (192.168.43.252) between the first and second instances.

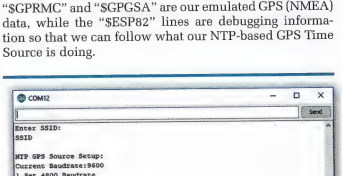


Fig.9: the NTP GPS Source set-up menu.

Parts list – NTP Time Source

1 D1 Mini ESP8266 module [eg, Jaycar XC3852] ***or***
1 ESP-01 module [eg, Cat SC3982 & Altronics Z6360]

To program the ESP-01, add:
1 USB/serial converter
[eg, Silicon Chip Online Shop Cat SC3543]
1 small breadboard
2 10kΩ 0.25W resistors (1% or 5%)
2 male-to-male jumper wires (to suit breadboard)
11 male-to-female jumper wires (to suit breadboard)

These two groups of three lines show the data from a configured module that has already connected to a WiFi network. You can see that it updates its time, latitude and longitude between the first and second group of sentences (it really is that quick!).

You will probably see something that looks like the first group repeated, as your unit will not be connecting to a WiFi network just yet.

To enter the configuration menu, type "~" and press enter on the Serial Monitor. You will need to have the serial monitor set up to produce carriage return (CR) or carriage return/line feed (CR/LF) at the end of each line, as the menu looks for CR on some commands; this happens by default.

The menu will appear, as shown in Fig.9. You will need to configure options three and four to suit your local Wi-Fi network by pressing "3" and Enter, followed by your WiFi network's SSID name and then press Enter. Then type "4" and Enter, followed by the password and Enter.

As you might imagine, the password is saved in a non-secure fashion and can easily be viewed by anyone who has access to the module, so be careful who you give it to.

The NTP server and dummy coordinates should not need to be changed but this can be done in a similar fashion if necessary.

The dummy coordinates correspond to Sydney, so should be a good default if you are using the High Visibility 6-Digit LED GPS Clock in Victoria, NSW or ACT. If you are using the GPS-synchronised Analog Clock Driver, these don't matter, as the time zone is set in the PIC on the driver PCB.

In any case, the unit should get a reasonably accurate latitude and longitude from the IP web service. It's only in the case that this fails that the defaults are used.

Finally, press "9" and then Enter to save, then press the reset button on the side of the D1 Mini to load the new defaults. You should see a valid IP address appear after the second comma of the "$ESP82" sentence if the WiFi connects successfully. See Fig.8 for more detail on this.

Checking the "$GPRMC", "$GPGGA" and "$GPGSA" sentences should reveal valid data, including the current (UTC) time and date after "$GPRMC". If everything seems to be working here, we can connect it up to our clock.

The D1 Mini also has an onboard LED to help set-up and troubleshooting. While it is looking for a WiFi network at start-up, the LED is on solidly – so if the LED lights up and never goes out, the unit is not connecting to your WiFi network. After this, the LED will blink every time data is transmitted, which should be once per second.

Configuring the ESP-01

As well as needing the right combination of pull-ups and pull-downs to be programmed, the ESP-01 will also need to be configured to run correctly before connecting it to a clock. Fortunately, this is easily done by adding solder bridges to some of the pins to connect them to the correct voltage levels.

Soldering the pins simply prevents the ESP-01 from entering programming mode, so it can still be configured via the setup menu on the serial port if necessary.

Carefully run a bridge of solder between the 3.3V pin (the top left pin when looking at the top of the board, pins at the top), CH_PD, RST, GPIO2 and GPIO0 (the four centre pins). This effectively forces the ESP-01 into run mode every time it is powered up. We found it easiest to bridge out the four centre pins, then tilt the module to allow the bead of solder to reach the 3.3V pin.

See the photo below for how the ESP-01 should look after it has been bridged. Alternatively, you could solder a couple of short lengths of hookup wire to join the pins.

To connect it to the clock, plug jumper leads into 3.3V (top left), GND (bottom right) and TX (above GND). From now on, the ESP-01 can be treated like the D1 Mini and these are the only three connections you need. Note that with the ESP-01 module, the blue LED is connected to the TX pin, so it will flicker to indicate data is being transmitted but will not solidly stay on while the module is attempting to connect to WiFi as with the WeMos board.

Connecting to the GPS-synchronised Analog Clock Driver

There are only three connections needed to work with the GPS-synchronised Analog Clock Driver from February 2017: power (3.3V), ground and the serial data. Remove the battery from the Clock Driver, ensure that JP1 is set to the 3V position, then wire the unit up to the GPS module header. See the top photo opposite for details.

This means connecting the 3.3V pin on the D1 Mini to the VCC pin on the clock, Ground ("G") to GND and TX to TX. We used jumper socket lead off-cuts to wire up our

Bridging the pins of the ESP-01 with solder forces it into "run" mode and prevents it stalling in UART upload mode. With a bit of care and a solder sucker, the solder can be removed and the ESP-01 can be reprogrammed if necessary. The pins that are bridged are VCC, CH_PD, GPIO0, GPIO2 and RESET. The copper tracks at the bottom of the PCB are the on-board antenna.

D1 Mini, so it's easier to remove in future if necessary (for example, if we need to configure it to a different WiFi network).

You'll see in the photo that we've actually connected 3.3V to the "EN" pad on the PCB, because it's directly connected to V_{CC} on the reverse of the clock PCB and it means that the wires don't need to cross.

Set the hands of the clock to 12, and re-insert the cells. You should see the STARTUP LED on the Clock Driver flash once, then twice as it powers up the D1 Mini. If the D1 Mini's LED does not light, check the wiring connections.

The LED should go out again in a few seconds as it connects to WiFi, and provided the Internet connection is good and the NTP servers are online, the STARTUP LED on the Clock Driver will flash four times and it will start double-stepping towards the correct time.

Connecting to the High Visibility 6-Digit LED GPS Clock

The set-up for the High Visibility 6-Digit LED GPS Clock, from the December 2015 and January 2016 issues, is similar to that for the GPS-synchronised Analog Clock Driver. Because our prototype unit did not have a 1PPS output (and it is not required by the clock), we did not connect it. If you need it, it's on pin D2 of the Mini.

Ensure that LK1 is set to the 3.3V position and connect +V to 3.3V on the D1 Mini, GND to G and TX to TX, as shown in the photo below.

Power on the clock, and after a few seconds, you should see the GPS display indicating that the clock is awaiting a valid GPS signal. Once valid data has been received by the clock, it will go to the normal clock display. Since this clock uses latitude and longitude to set the time zone, incorrect data here may lead to an incorrect time being displayed.

If you find the time is incorrect (especially if it is out by a whole number of hours), the NTP-based GPS Time Source may not be providing correct latitude and longitude data, in which case the dummy values may need to be changed.

The NTP-based GPS Time Source updates its time from the NTP servers every hour. We've tried to program it so that it won't "jump" when that happens; in fact, you probably won't notice it. But for the first few hours, as the drift compensation will not be operational yet, you may notice an occasional slight glitch in the time.

Using it with other clocks and NTP servers

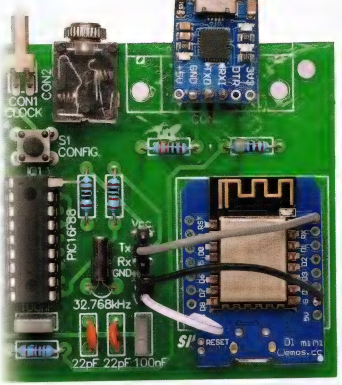
Any device that uses GPS data as its clock source should be able to use this project. With NTP being used so widely, the time provided is quite accurate and the three connections for power, ground and data are usually easy to find.

The default NTP server used in our sketch is actually provided by volunteers who donate their server time to make NTP widely available. See http://www.pool.ntp.org/en/ for more information.

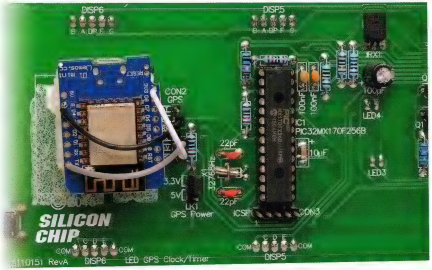
As always, servers on the internet may come and go, and there are alternatives. For example, nist.time.gov is provided by the US government, and it was a server we tried while testing the NTP-based GPS Time Source. In practice, because the servers are so far away, the round-trip time for our data was too long to maintain accuracy, so a closer server was chosen at pool.ntp.org

This server is actually a large number of servers around the world and the internet's DNS system tries to point you to a nearby server.

The server can be changed via the configuration menu by pressing "5" and enter, then entering the URL or IP address of the new server.



Only three wires are needed to connect the D1 Mini to the GPS-synchronised Analog Clock Driver (Feb 17) and although slightly larger than the GPS Module, the D1 Mini is a great fit for the PCB.



Using a row of header pins makes it much easier to connect our completed unit to the clock. In this case, we only need three pins.

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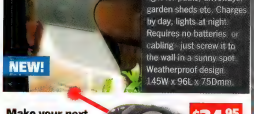

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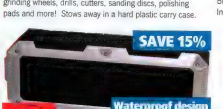

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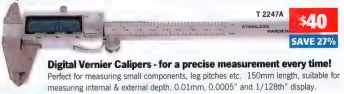

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B 6508

A Different Approach in Digital Hearing Aids: BlameySaunders' "Facett"

by Ross Tester

Having worn three different types of their hearing aids since 2011 when BlameySaunders first entered the market, I was intrigued to find they were once again launching a completely new model, with a slogan "Hear Like Never Before". What could be so different – after all, it's only been 12 months or so since they introduced their brilliant Opus96 digital models?

The first thing you notice when you open the Facett Hearing Aids packaging is that the contents look quite different from previous models.

For a start, they don't come with the bulky "Sound-N-Dry" storage container with tiny beads that go everywhere when the bag splits!

Instead, they have what they call a "Pod", a portable storage case/drier which houses the hearing aids themselves. But is much more than a storage case and drier.

For a start, it has a power socket on the side – that's used by the inbuilt battery recharger.

Battery recharger?

Well, that's certainly different – the Facett uses rechargeable battery modules. That on its own is a very welcome change.

Each of the charged cell modules will give up to 36 hours continuous use.

Anyone who has used hearing aids for a while will tell you that continually buying replacement batteries is more an inconvenience than a huge cost – but a cost nevertheless.

For the common "312" size zinc-air cells to suit the Opus96 (or the "13" size to suit the Symphony), for a box containing 60 cells I usually paid about $25 for relatively unknown brands and up to about $50 or so for brand names, so somewhere between 40c and $1.00 each.

But every now and then (eg, when I forgot to take a battery pack with me on holidays!) I had to buy a pack from

Woolies or Coles to get me through – and these could be as much as $10-$12 for a 6-pack! $2 each? Ouch!

Incidentally, you can get *really* caught out buying hearing aid batteries on-line if you don't read the "fine print": I found a pack of 18 batteries for $7.57 on ebay – **plus $90.14 postage!** (That's *only* about $5.40 EACH! Ouch^2!).

Zinc-air batteries start discharging as soon as you remove their sticker, which allows air to enter and "activate" them. Then they only last a few days.

Perhaps even worse, the tiny disposable batteries act like a magnet to toddlers – straight into the mouth!

While zinc-air batteries are not supposed to be as dangerous as lithium cells (which have caused severe injuries and even deaths when swallowed) I still wouldn't like to take the chance of zinc-airs being swallowed.

But back to the Facett: it uses tiny silver-zinc rechargeable cell modules which instantly attach, magnetically, to the hearing aid "core".

This also causes the tiny contacts on the cell to mate with the contacts on the core.

And being magnetic, they will only attach one way (if you try to put them on back-to-front they will instantly "flip" to the right way – driven, of course, by the strong magnetic field).

You only have to get the cell module close to the core – say 10mm – and they instantly snap into place.

That same magnet-based connection is used when charging the cells in the pod. When inserted, LEDs in the pod flash green as the cells are being charged, switch to solid green to show they are charged, or turn red if there is a problem (eg, cells won't take a charge).

There are four charging "ports" in the pod as well as two "idle ports" – they (magnetically, again) hold the cell modules without charging them – so you can have two charged modules ready for use while charging up to four modules.

It takes around eight hours to charge a cell module from flat so overnight is the go, much like my mobile phone (or even my electric car!).

The pod is powered, via a portal in the end, from a 5V source – either a USB outlet on a PC, tablet or laptop, or the 5V mains adaptor (supplied). To connect, a standard USB-to-micro USB cable is also supplied.

Three of the battery modules are shown in charging positions; the left-hand one is in the "idle port" (for storage). The "core" modules are the hearing aids themselves – the Red speaker is for the right ear, the bLue speaker for the left.

As we mentioned earlier, the pod also stores, and keeps dry, the two hearing aid cores themselves, also held in position magnetically.

To keep the hearing aids dry, a replaceable desiccant clips into the top of the pod. As with all desiccants, it warns you not to eat it . . .

Emergency batteries

Having extolled the virtues of the rechargeable cell modules, what if you are out the back of Woop Woop for a few weeks and have no access to power?

Admittedly, that would be pretty rare these days, especially with most cars having 5V USB sockets, or solar chargers for mobile phones and the like (which would obviously charge the Facett hearing aid modules) but it is possible.

BlameySaunders have foreseen this situation and will soon have an optional cell module which does accept traditional (size 13) hearing aid batteries.

But we have to say this is something that we wouldn't be concerned about.

Bluetooth link

Also on the drawing board and due to go on sale later this year will be a wireless (Bluetooth) link which, among other things, transmits audio from a mobile phone, media player, etc, direct to the Facett hearing aids.

It will also help in carrying out a conversation in background noise and even let you change some of the Facett parameters (volume, for instance) from a smartphone or similar device.

But as we said, this is in the future.

Physically . . .

The Facett hearing aid, with attached battery, is slightly larger and heavier than the Opus96: 23 x 7mm and 2.4g for the Opus96, 31 x 8mm and 4.0g for the Facett.

While this might sound significant (particularly the weight), in both cases, I forget that I'm wearing them within a few minutes. In fact, that can be a trap

Straight outa the box . . . or in this case, only the Pod, complete with the Facett charging dock with hearing aid "cores", the battery modules (4), the dessicant (it slots into the circular retainer in the lid) and instructions.

for young players – a few times I've nearly dived into the pool or jumped under the shower wearing my hearing aids – fortunately, *nearly*!

I trialled the gold-coloured Facetts; they are also available in silver, grey and charcoal colours. Obviously, the Facett gets its name from the multi-facetted case design.

There is only one control as such on the Facett but it serves a dual purpose. It is an up/down volume control when pressed briefly; hold the toggle button in and it switches between the normal ("Everyday") program and programs which you enter yourself, such as in a crowd, or watching sport, or watching TV, for example.

(We'll look at programming the Facett shortly).

The control reverts to volume when the Facett is turned off (ie, the battery is disconnected – there is no on/off switch as such).

Inside the hearing aid

According to BlameySaunders, the electronics in the hearing aid are not overly different to the Opus 96 models released last year.

Those hearing aids were highly innovative – digital processing (of course!) with 96 channels, multi-channel adaptive directional microphone and so on.

I remember saying at the time they were a noticeable improvement over the previous models, which I reviewed in March 2013.

The main innovation in the new Facett hearing aids is in the construction and battery connection, and that IS highly innovative, as mentioned earlier.

BlameySaunders engineers told me that given the short window of opportunity, they've used that time to "up-spec" and tweak the circuitry and components in the Facetts, making them the best that (current) technology allows.

So the improvements they've made earn the Facetts the title of "flagship" in the BlameySaunders fleet.

Virtually invisible

One of the advantages of "behind the ear" hearing aids, with their "speaker in ear" (SIE), is that they are for all intents and purposes invisible – especially for ladies with longer hair which may cover the ears (and therefore hearing aid).

Wearing hearing aids is sometimes equated with "getting old" and many people are reluctant to admit that, despite what the calendar says!

(The alternative is also true . . . continually saying "eh?" or "waddya say?" is also a sure sign of deteriorating hearing/ageing!)

From the hearing aid itself, there is a tiny (~1mm) clear tube which goes from behind the ear to the front and follows the contour of the ear, with the miniature (~11mm long x 3mm diameter) speaker at the end.

Some users prefer to simply place this inside the ear canal; others prefer to use one of the (supplied) ear tips which simply slide over the end of the SIE and lodge the speaker a little more firmly in the canal.

Personally, I find this has both disadvantages and advantages: I find the ear tips take a little getting used to, making me continually think that there is something in my ear (which, of course, there is!).

The advantage is that external sound, which hasn't been processed or tailored by the hearing aid, is to some extent blocked.

This can be a real boon in a noisy environment/crowd/etc, especially if you set up a program to tailor the sound appropriately.

Apart from the half dozen or so spare tips, in various sizes, supplied to suit the Facett, different size tips are available from BlameySaunders. They recommend fresh ear tips every 4-6 weeks.

Some of the ear tips have holes in them which allows some "natural" sound to enter as well as that from the hearing aids, while other tips are solid, blocking any sound/noise not processed by the hearing aid.

The "Everyday" program

Even if you have no intention of buying hearing aids, you can check your hearing without obligation using BlameySaunders' "Speech Perception Test". See the panel "On-line Speech Perception Test".

You might be surprised to find that your "perfect" hearing ain't necessarily so!

If you do go ahead and purchase BlameySaunders hearing aids, they use the results of the Speech Perception Test to program them with the "Everyday" program your hearing aids starts with when they are turned on (you actually hear them say "Everyday").

Therefore, every "Everyday" program is unique, tailored to your hearing loss. No two people will have exactly the same losses or requirements.

Hearing Loop

By the way, there is a second "pro-

gram" automatically loaded into the Facetts, selected by holding down the up/down button. That accesses the "Hearing Loop" or "Telecoil" function.

We covered Hearing Loops in detail in a DIY series published in September and October 2010 (siliconchip.com.au/series/11) but in a nutshell, a Hearing Loop is a large coil of wire placed around a meeting room/auditorium/theatre/church/etc, fed by a relatively high-powered amplifier.

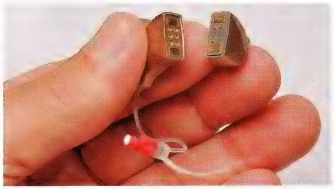
These loops are designed to allow the program, service, etc which others are listening to via a PA system to be directly induced into hearing aids fitted with the appropriate firmware.

Hearing Loops are now installed in many, if not most public buildings and this trend is expected to continue for the vast majority of new public buildings in the future.

Most hearing loops are installed in a building hidden in walls, under floors, etc and where they are present you will see a blue and white hearing loop logo.

Often, signs inside the building will tell you exactly where the hearing loop is situated – you have to sit inside the loop for it to work with your hearing aids.

The Telecoil part is slightly different but works much the same way – this refers to special telephones designed to amplify incoming calls and induce the signal direct to hearing aids. Again, they are intended for the hearing impaired.



This shot gives you the relative sizes of the hearing aid "core" (the right one in this case with its red speaker) and its battery module. This was about as close as I could get them without them magnetically "snapping" together.

IHearYou/Incus-M

As we mentioned, the Everyday program relies on the words you recognised in the on-line test – and while it's much better than a tone-based test, it's not entirely foolproof.

For example, you might be distracted while listening and miss a word or two, or your speaker/headphone setup might not be quite up to scratch.

You only get one bite at the cherry – or in this case, one listen. And if you miss it . . .

The analysis software used by BlameySaunders may well treat this as a hearing deficiency and adjust the program parameters accordingly.

In this case, you'll want to adjust the Everyday program. Or you might want to add your own programs to suit your particular requirements, as we mentioned earlier. You can add up to three more programs.

You do this by means of BlameySaunders' "IHearYou" software (a free download) in conjunction with the Incus-M programmer, supplied with your hearing aids. IHearYou is available for Windows, Android and Mac platforms and suits PC, tablets or smartphones.

The Incus-M is slightly different from the earlier Incus programmer – the earlier models have a flexible flat cable (FFC) which must be inserted the right way around into the hearing aids. To be honest, I found this rather fiddly and despite instructions, managed to insert them back-to-front on more than one occasion.

The Incus-M has the same magnetic "instant connection" as the battery modules making instant, positive connection.

Now you just bring the Incus-M cable ends close to the core modules and they snap into place (red for right hearing aid, blue for left, just like everything else).

When you've done that, you can set the balance between ears (that's where my Everyday program was most deficient) overall volume levels and so on.

Incidentally, we looked at the Incus programmer in some detail in our September 2014 issue (siliconchip.com.au/article/8005). There are a few updates but overall operation is very similar.

The Incus-M programmer with its core connection cables, the USB power cable above and 230V USB adaptor at right. The Bluetooth module worked perfectly with my Android phone but so far, steadfastly refuses to talk to my PC!

A few teething problems – or is it the nut on the keyboard?

Even having gone through this procedure last year with the Opus96 hearing aids, I had a lot of difficulty getting my PC to recognise the Bluetooth "dongle" supplied by BlameySaunders.

Despite spending considerable time

with Sophie from BlameySaunders and, indeed, one of their techs actually taking control of my computer remotely from Melbourne (with TeamViewer software), the problem is as yet unresolved.

I am fairly certain the problem is at my end, something my computer doesn't want to do – even if I sit and yell at it!

No problem, though, when we tried the alternative: using my (Android) mobile phone. It found the Bluetooth hardware immediately, loaded their "IHearYou" software and then allowed me to program the hearing aids easily, using the Incus-M.

The range of adjustments is quite extensive, ranging from setting the overall volume (using five tones) by sliding control bars on the phone screen, setting the balance between those tones in a similar way, adjusting the sensitivity for minimal feedback, changing the parameters so that certain sounds wouldn't be too loud or too soft, and so on.

This is all quite self-explanatory once you're in the software – we've shown a few screen grabs to give you some idea of what is happening.

Okay, what's the verdict?

Every time I've road-tested a new model hearing aid from BlameySaunders, I've been impressed with the improvement.

Sure, in some cases it's only little improvements between models but those little steps add up to quite a significant upgrade – an upgrade well worth making.

On the Facetts, the first thing I noticed was the feedback (or more to the point, the lack thereof). I'm not sure what the engineers have done to make such an improvement in this area, but it was really noticeable.

The second was the ease-of-use. I've already covered the battery connection and charging, and also the single up/down control – these two things alone make for a real improvement.

Third is that "pod" – yes, it is the recharger but it's also well thought out for hearing aid storage and drying as well as recharging.

And the fourth was simply the clarity: they just seemed to make sound clearer. I've commented in the past that television program voices, particularly female voices and more particularly on UK-originated shows, have always sounded somewhat muffled to me. The Facetts have largely overcome that problem.

As far as the improvement of the Facetts over the Opus96, I'm sure there was a marginal improvement in the new model.

Maybe, in the normal course of events, it might not be enough to convince me to upgrade. After all, even at the prices BlameySaunders sell their hearing aids for, hearing aids are certainly not cheap!

But even if it was ONLY that new rechargeable and so easy-to-use battery system – and the amount of money I would save by not forever buying throw-away batteries – I'd upgrade to the Facett hearing aids in a heartbeat! It really is that much of a breakthrough!

And they look pretty fancy, too . . .

What's in the box?

When you receive your Facett kit, you'll not only find the two hearing aid cores, four rechargeable battery modules and the charger/storage Pod, but the Incus-M programmer will also be included (elsewhere, if such a device is offered at all, it can be several hundred dollars extra).

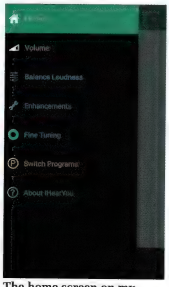
Along with this, there is a selection of ear tips, wax-stop plugs and cleaning equipment plus, of course, instructions.

And speaking of instructions, if there is anything that's not overly clear, I have to report that the phone assistance is outstanding!

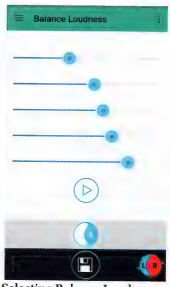
They patiently took me through some of the less obvious features (eg, how to virtually eliminate feedback or how to minimise sudden, sharp sounds). They were also the ones that told me about the Telecoil function which I'd missed completely.

If you go on-line (**www.blameysaunders.com.au**) in working hours, the chances are very high that someone will pop up in a chat window and ask if you need any help (and they do – help, that is!).

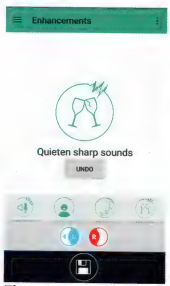
If you're not sure which hearing aids you need, they'll help you with that decision without applying the sort of pressure you'd get in a shop-front hearing aid store to "upsize", as the



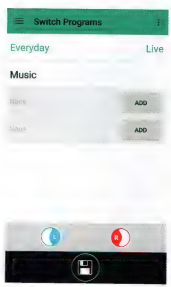
The home screen on my Android phone which gives access to all the other programming functions.



Selecting Balance Loudness reveals these five tone bars – simply slide them along until they all sound level.



There are some quite specialised controls under "Fine Tuning" such as this "Quieten Sharp Sounds".



Switching programs allows you to set up (and tailor) individual programs to suit your particular needs.

fast food retailers like to say.

If you just want to browse, or view information, just ignore the chat.

How much, where from:

If you've priced hearing aids lately, you'll know that many shop-front hearing "specialists" (and they seem to be popping up everywhere!) can quote you around $12,000 per pair for good digital models – and often more.

The Facett hearing aid package from BlameySaunders will cost you exactly half that amount – $5990 per pair – a not inconsiderable amount of money, to be sure, but that is for one of the most advanced hearing aids on the market.

BlameySaunders still have all three of the hearing aid packages available which we've reviewed over the years in SILICON CHIP – the "Symphony" 32 Channel, entry level hearing aid at $1415 each/$2830 per pair (reviewed in July 2011 [siliconchip.com.au/article/1066]); the SIE-Plus 64 Channel mid-range at $2770 each/$5440 per pair (March 2013 [siliconchip.com.au/article/3299]); or the (until now!) top-of-the-line 96 Channel Opus-96 at $2635 each or $5270 per pair (May 2017 [siliconchip.com.au/article/10653]).

And yes, you can buy individual hearing aids if (a) you don't need two – but BlameySaunders will tell you that if you need one, the odds are you do need two! Or (b) you've managed to misplace one – or, as I mentioned when I reviewed the Opus 96 hearing aids, our schnauzer decided one looked like a little bone and . . .

Don't forget, too, that private health insurance funds usually offer rebates on hearing aids – the better funds about $1200; others can be quite miserly!

Where to buy

You can buy on-line from the same website with a 100% money-back guarantee. Or, if you're in Melbourne, Sydney or Brisbane, you can book an appointment at any of the BlameySaunders clinics (addresses and even location maps are on the website; all three are in or near the heart of the cities).

You can also do the Speech Perception Test at those centres and, of course, have explained to you the different types of hearing aids and their features. SC

Acknowledgement: Our thanks to Dr Sophie Brice from BlameySaunders for her assistance.

Checking Your Hearing Online

BlameySaunders maintain that there are five key indicators that your hearing is not all it should be (or once was!).

(1): You find it hard to follow a conversation in a crowded room or restaurant.
(2): You feel that people are always mumbling.
(3): People complain about the volume you set the TV or radio to.
(4): You find it easier to understand men's voices than those of women and children.
(5): You often experience ringing or whistling in your ears.

If you recognise any (all?!!!) of these, maybe it's time your hearing was professionally checked.

You can go to a shop-front hearing aid retailer who will, most likely, put you through a series of tones asking you to push a button when you can either hear, or not hear, the tones. From this, they produce an "audiogram" which graphs the levels you can hear at various frequencies.

The problem with this is it is very subjective: eg,"did I *really* hear that?" And then follows, of course, the pressure to purchase hearing aids that are often way overpriced!

Everyone in audiology and hearing science is aware of the inadequacies of the pure tone audiogram. All that tells you is how softly you can hear beep sounds. From there, the tester has to try and explain why you are having trouble hearing.

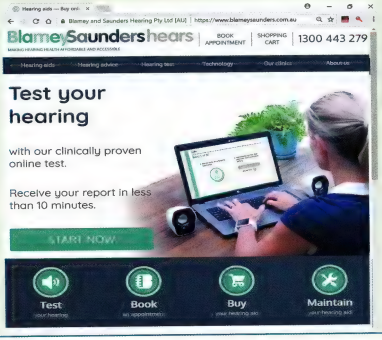
The pure tone audiogram's role should be only the first part of trying to find out the medical cause of your hearing difficulty – it takes a trained professional to determine the actual cause.

Instead of pure tones, BlameySaunders developed a "Speech Perception Test". You listen to a randomised list of 50 phonemically-balanced English words and type what you hear in the box provided on screen. They measure the words you hear or miss against the speech features that make up each word (eg, phonation, resonance, intonation, pitch, sibilants, vowels, hard and soft consonants etc). This is analysed to give the information needed to set up your hearing aids but also tells you how much difficulty you have with the different sounds of speech. This clinically-proven test enables them to generate an accurate report on the real-world speech sounds you *are* able to hear.

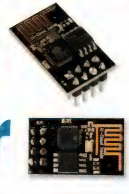
You can do the BlameySaunders Speech Perception Test online, anytime, without obligation. All you need is a relatively quiet room with good speakers or headphones connected to your PC. The test generates a report which will be emailed to you within ten minutes or so.

Whether you decide to go ahead and invest in hearing aids after receiving this report is entirely up to you. If you do decide, they'll guide you all the way.

Simply go to the BlameySaunders.com.au website and you'll be greeted with a "Test Your Hearing" splash screen. From there, follow the prompts.



The ESP-01 WiFi Data Transceiver



The ESP-01 is a very popular WiFi transceiver module based on the ESP8266 IC; which is designed to allow almost any microcontroller to connect to a WiFi network. To make this as easy as possible, the chip is programmed to respond to Hayes AT modem text commands. As well, the chip can be re-programmed to perform a variety of different tasks.

WiFi networking has been around now for 20 years, after being adopted as a standard protocol in 1999 – the same year the WiFi Alliance was formed. Since then it has grown steadily in popularity, especially in mobile devices. It's also quite handy for wirelessly connecting computers to routers/modems and peripherals like printers.

Responding to this growth in WiFi popularity, in mid-2013, Chinese semiconductor manufacturer Espressif Systems (based in Shanghai) released its ESP8266 chip. This is a complete SOC (system on a chip), combining a 32-bit RISC (reduced instruction set computer) microcontroller with a full TCP/IP (internet protocol) stack and all of the components needed for a WiFi data transceiver.

But the ESP8266 didn't really make an impression in the Western world until 2014, when another Chinese firm, AI-Thinker, released its ESP-01 WiFi transceiver module. This was based on the ESP8266, but what made it particularly popular was its cost at less than $4.00.

So the ESP-01 module and the ESP8266 chip are not new; they've been around for over three years. In fact, Geoff Graham wrote an article on using the ESP-01 module in the December 2014 issue of SILICON CHIP, titled "The $5 WiFi Server".

The ESP8266 has since been used in:

- a WiFi Christmas light controller (Circuit Notebook, December 2016, siliconchip.com.au/Article/10486);
- as a data logger that uploads to the cloud (September 2017, siliconchip.com.au/Article/10804);
- in the Water Tank Level Meter in the February 2018 issue (siliconchip.com.au/Article/10963);
- and most recently, the NTP Time Adaptor for GPS Clocks that we just published in this issue.

Those projects actually featured different modules based around the ESP8266 chip; there are dozens of different boards, many of them designed to be compatible with the Arduino system. Most of the information in this article regarding the ESP-01 applies equally to those other ESP8266-based modules.

We are taking a closer look at the ESP-01 module and ESP8266 chip here since they have numerous WiFi and "Internet of Things" (IoT) applications.

As an aside, Espressif has recently released a follow-up to the ESP8266 chip: the ESP32 series, which incorporate WiFi & dual-mode Bluetooth transceivers and dual-core micros.

Although modules using the ESP32 chips have started to appear, their prices are significantly higher than that of the ESP-01 at around $9.00. But the ESP-01 still has some other advantages, such as lower power usage in some situations. This has renewed interest in the ESP-01, especially since it's the easiest way to get started with WiFi at the lowest cost.

About WiFi

WiFi is a technology for wireless local area networking, with devices complying with the IEEE 802.11 protocol standards. A large part of this is based on a patent (US5487069) developed at the CSIRO in Australia, by a

Table 1: IEEE 802.11 Network PHY Standards commonly used for WiFi

Protocol	Frequency (GHz)	Bandwidth (MHz)	Stream data rate (Mbit/s)	Modulation	Approximate range (m)
802.11b	2.4 – 2.5	22	1, 2, 5.5, 11	DSSS	35 indoors, 140 outdoors
802.11g	2.4 – 2.5	20	6, 9, 12, 18, 24, 36, 48, 54	OFDM	38 indoors, 140 outdoors
802.11n	2.4/5.25-5.35	20/40	6.5–65/13.5–135*	MIMO-OFDM	70 indoors, 250 outdoors
802.11a	5/3.7 (USA)	20	1,2	OFDM	35 indoors, 120 outdoors
802.11ac	5.25–5.35	20/40/80/160	6.5–86.7/58.5–780*	MIMO-OFDM	35 indoors
802.11ad	60	2,160	Up to 6.75 Gbit/s	OFDM	60 indoors, 100 outdoors

DSSS: Direct Sequence Spread Spectrum OFDM: Orthogonal Frequency Division Modulation
MIMO-OFDM: Multiple Input, Multiple Output antennas with OFDM
* Figures using ¤ guard interval (GI) of 800ns

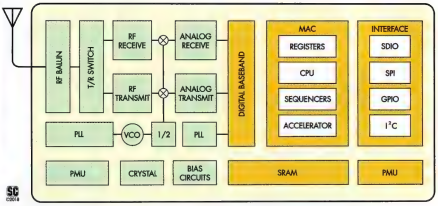


Fig.1: block diagram of the ESP8266 IC. The left-hand side of the diagram contains the RF sections while the right-hand side is the baseband and CPU section.

team led by radio astronomer Dr John O'Sullivan.

The IEEE 802.11 protocol was first released in 1997 and has since been revised and updated numerous times. 802.11 is a set of MAC (media access control) and PHY (physical layer) specifications for implementing WLAN (wireless local area network) data communication in the 2.4GHz, 3.6GHz, 5GHz, 5.9GHz and 60GHz frequency bands.

There are many different versions of the 802.11 protocol. Those that are most popular for WiFi are 802.11a, 802.11b/g/n and 802.11ac. These mainly differ in terms of their PHY specifications, as shown in Table 1.

The ESP8266 chip

The ESP8266 is a self-contained WiFi networking transceiver and microprocessor, packaged in a single 32-pin QFN SMD chip measuring only 5 x 5mm. It operates in the internationally unlicensed 2.4-2.5GHz ISM (Industrial, Scientific and Medical) band and is compatible with the 802.11b/g/n protocols.

The downside to the 2.4-2.5GHz band is that it is also used by Bluetooth devices, microwave data transceivers using the Nordic nRF24L01+ chip and also plagued with various sources of noise like microwave ovens. So this is a somewhat noisy band, and becoming noisier all the time.

The block diagram of Fig.1 shows what's inside the ESP8266. On the left are the RF sections, including the transmitting and receiving sections, the T/R switch, an LNA (low noise amplifier) and an RF balun for connecting to one or two antennas.

On the right is the baseband section which includes an integrated 32-bit RISC CPU, a memory controller with both ROM and SRAM, all of the registers and sequencers for implementing a full TCP/IP stack and interfaces for SDIO (SD cards), SPI (serial peripheral interface), GPIO and I²C communication with external MCUs and/or external flash memory.

Incidentally, the RF output power in 802.11b mode is +19.5dBm, or just under 100mW. When this output is being provided in transmit mode the chip's current drain from the 3.3V supply is 215mA, corresponding to around 710mW.

In receive mode with 1024-byte packets, the current drops to around 60mA (<200mW). The chip also has two power saving modes: standby mode, where only the RTC and watchdog remain active (current <1mA) and deep sleep mode where only the RTC remains active and the current falls to below 12μA. The chip can be woken up to transmit packets in less than 2ms.

The ESP-01 module

The ESP-01 module is quite small, measuring only 25 x 14.5mm, including the PCB track antenna and the 8-pin interface connector.

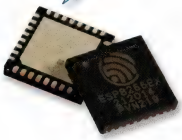
Fig.2 shows the complete circuit for the latest version (V2) of the ESP-01 module and there's very little in it apart from the ESP8266EX chip itself, a tiny 26MHz crystal and a 25Q80 1MB flash memory chip. There are two LEDs, one to indicate when the module is powered up (LED1) and the other to indicate when serial data is being transmitted (LED2).

All of the connections to and from the external micro are made via CON1 at upper left.

The module is designed to operate from 3.3V and should not be connected

ESP8266 Features

WiFi – 802.11b/g/n
32-bit RISC CPU
512KB-16MB flash memory
HTTP & FTP
IPv4
TCP/UDP
17 GPIO pins
SPI
I²S and Software I²C
10-bit ADC



The ESP8266 is a low-power, self-contained WiFi chip.
The main use of the ESP8266 is to provide a WiFi interface for other microcontroller devices.
However, the ESP8266 IC is powerful enough to be used as a low-power computer, combined with being able to flash the firmware with your own program code using a bootloader.
It has an extensive API provided on ROM which implements various timer, hash (MD5 & SHA1), WiFi and TCP/UDP functions etc.
A list of API functions can be found at:
siliconchip.com.au/link/aaj4
siliconchip.com.au/link/aaj5

Some potential uses include:
Remote file manager
Web server
Ad-hoc network
Data logger
Baby monitor

What is it?

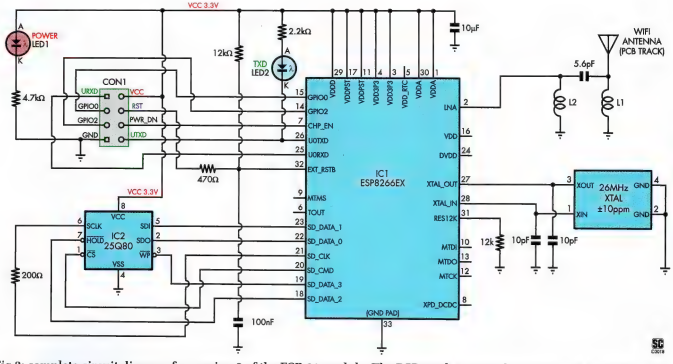


Fig.2: complete circuit diagram for version 2 of the ESP-01 module. The PCB track antenna has a range of approximately 300m under good conditions with line of sight and possibly 10m at best indoors.

to a 5V supply. The logic inputs of the ESP8266EX are not tolerant of 5V, so if your external micro operates from 5V the interconnections need to be made via logic level translation circuitry. We have read that applying 5V to its input pins does no harm but this is an undocumented feature and we don't suggest you rely on it.

Another point to note is that the ESP8266EX chips used in the latest versions of the ESP-01 module (V2) are programmed to communicate with an external PC or micro at a default rate of 115,200 bps (baud), while earlier versions were set up for 9600 bps. This can cause complications when you try to use the newer ESP-01 modules with an Arduino Uno or equivalent.

Connecting to a PC

Interfacing the ESP-01 module with a computer is quite easy. All that's needed is a USB-UART bridge module to provide a communications link with the computer (via a USB port) and also to derive power from the computer via a 5V-3.3V LDO (low-dropout) regulator to reduce the supply voltage to 3.3V.

The basic circuit needed is shown in Fig.3, although we've shown two versions of the USB-UART bridge module – one with a micro USB socket and the other with a type A socket. Both use the popular CP2102 chip, for which there's a VCP (virtual COM port) driver in most versions of Windows, Linux and macOS.

Note that although the popular USB/UART bridge modules also provide a 3.3V output, this is generally only capable of supplying 100mA or so. That's why you need to use an additional LDO regulator, like the LM1117T shown, to provide for the higher current levels needed by the ESP8266 when it's transmitting data packets.

Your PC will be able to communicate with the ESP8266 and hook up to a local WiFi router and network, using a standard communications terminal program like Tera Term. Note that this won't give your PC direct access to the wireless network, since it won't have a network driver that understands how to communicate with the ESP8266.

Programming it directly

While you can use the ESP-01 module purely as a wireless "bridge", it's also possible to program the ESP8266 directly, ie, to run some code without a separate micro. That's because the ESP8266 does have a built-in CPU of its own, together with RAM and EEPROM.

In fact, ESP8266/Arduino enthusiasts have come up with a nifty

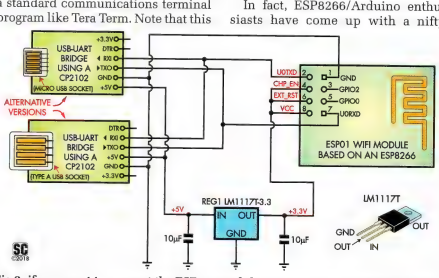


Fig.3: if you want to connect the ESP-01 module to a computer, all that's needed is a USB-UART bridge like the CP2102 and LDO regulator to reduce the USB port's 5V supply voltage to 3.3V.

Arduino board package which allows the ESP8266 to be programmed via sketches written in the Arduino IDE, using standard Arduino functions and libraries. Information about this Arduino "core" is available at https://github.com/esp8266/Arduino

Using it with an Arduino

Connecting the ESP-01 module to an Arduino is a little more complex than you might expect, mainly because of the need to power the module with its own 5V-3.3V LDO regulator and also because logic level translation circuitry is needed to interface between the module and an Arduino's I/O pins.

The easiest way to do this is to use a WiFi module interface shield like the Freetronics ESP1SH, as shown in Fig.4. The shield mounts on the top of an Arduino and provides an 8-pin header socket for plugging in an ESP-01 module and an LD1117 3.3V LDO to power the module plus logic level translation circuitry for the TX and RX data lines.

There's also a pushbutton switch (S2) for reprogramming the ESP-01's flash memory, another pushbutton switch (S1) to reset both the ESP-01 and the Arduino together and most importantly, an 8-way-by-3 header strip which allows you to link the level shifted ESP-01 TX and RX lines to one of eight possible pins on the Arduino.

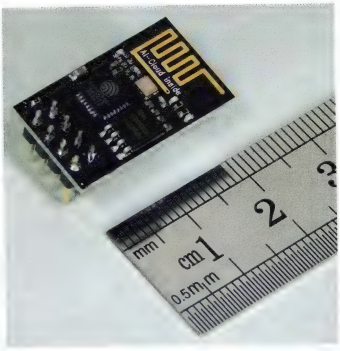
Link header

That link header on the ESP1SH shield is important because of the point mentioned earlier, about the latest ESP-01 modules being programmed to communicate at 115,200 bps. This a problem with the Arduino Uno and its clones because the ATmega328 CPU used in these modules has only one hardware UART, which is normally used for communication with the PC via the onboard serial/USB bridge.

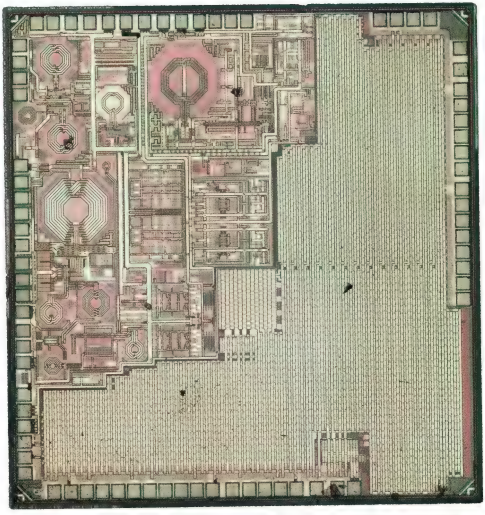
To communicate with another serial device like the ESP-01, you need to use a software-driven serial port with a different pair of pins for the TX and RX lines. But these software-driven serial ports can only operate at a maximum speed of 38,400 bps.

But there is a workaround. First, you download a do-nothing sketch to the Arduino and set it running, so that it ignores the hardware UART temporarily.

Then connect your ESP-01 module



An enlarged view of the latest ESP-01 module. It features a few SMD components including a 26MHz crystal and 1MB of flash memory. The GND pin is at the top-right of the PCB, while V_{CC} is at the bottom-left.



An enlarged photo of the silicon die and metal layers of an ESP8266 (a variant of the ESP8089). The RF section is at upper left and takes up a larger portion of the chip. The area below and right is memory while the I/O pads are along the edges. https://zeptobars.com/en/read/Espressif-ESP8266-wifi-serial-rs232-ESP8089-IoT

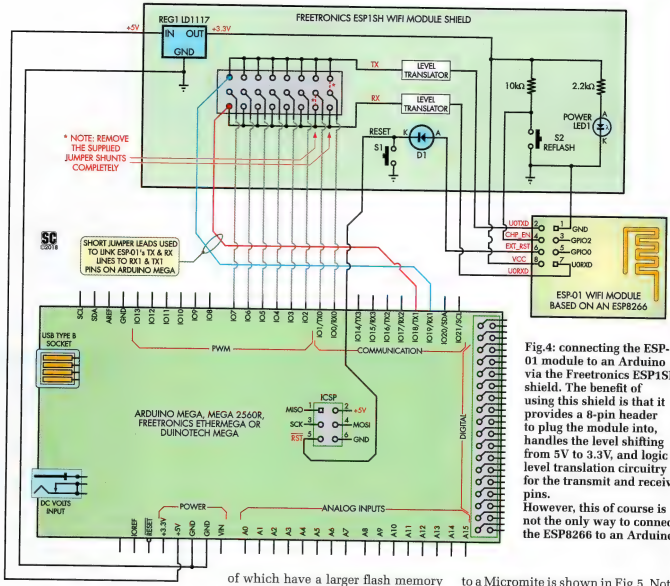


Fig.4: connecting the ESP-01 module to an Arduino via the Freetronics ESP1SH shield. The benefit of using this shield is that it provides a 8-pin header to plug the module into, handles the level shifting from 5V to 3.3V, and logic level translation circuitry for the transmit and receive pins. However, this of course is not the only way to connect the ESP8266 to an Arduino.

to the same hardware UART RX and TX pins (D0 and D1). You can then reprogram the ESP-01 directly from the PC so that it defaults to a data rate of 38,400bps or less, making it compatible with the software serial port.

Then reconnect the ESP-01 TX and RX lines to a different pair of pins on the Arduino and set those up as a software serial port.

Alternatively, you could simply use the hardware TX and RX pins to communicate with the ESP-01 with the limitation that you must disconnect it when re-programming the Arduino board. This will limit your use of the Serial Monitor for debugging, though.

Things are a lot easier if you use an Arduino Mega, Mega 2560R, Freetronics EtherMega or the Duinotech Mega, because these all use either the ATmega1280 or 2560 processors, both of which have a larger flash memory plus an additional three UARTs. Each of these can provide a serial port which operates at 115,200 bps or more.

The ESP1SH shield's header strip allows you to link up the ESP-01's TX and RX lines to any serial port you wish, without the need for reprogramming. In the case of the Mega2560R, all you need to do is connect the ESP-01 TX line to pin 19 (RX1) and the RX line to pin 18 (TX1) using a pair of short male-to-female jumper leads. This is shown in both Fig.4 and the photo at right.

We'll look at what's involved in programming an Arduino Mega to use the ESP-01 module for WiFi communication shortly. In the meantime, let's look at how the ESP-01 can be linked to a Micromite.

Connecting a Micromite?

How to connect an ESP-01 module to a Micromite is shown in Fig.5. Note that we still need to use an LM1117T LDO regulator to provide 3.3V to the ESP-01, since its current drain is somewhat higher than that available from the Micromite's own 3.3V regulator. But the TX and RX lines from the ESP-01 can be directly connected to the RX and TX pins of the Micromite, since no level translation is needed.

There's no problem with data rates either, providing you use the connections shown, which use the Micromite's hardware UART port (COM1). This can operate at 115,200 bps without any problems, provided you are running the Micromite at a clock frequency of 40MHz (the default), 50MHz, 30MHz or even 20MHz.

WiFi via the ESP-01

Because the ESP8266 chip in the ESP-01 module is designed to communicate via standard Hayes AT modem

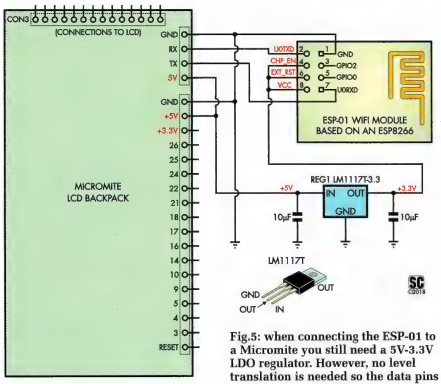


Fig.5: when connecting the ESP-01 to a Micromite you still need a 5V-3.3V LDO regulator. However, no level translation is needed so the data pins can be connected directly.

text commands, using it to add WiFi capabilities to your microcontroller project is relatively easy. All your Arduino sketch or MMBasic program needs to do is set up the ESP8266 chip using the appropriate AT commands, and then respond to the data it gets back from the ESP8266.

If this sounds a bit daunting, you can find a list of all the commands here: siliconchip.com.au/link/aaj7

If you want to use the ESP-01 module with a Micromite, you'll get a lot of help and guidance by studying a program that Micromite guru Geoff Graham wrote to accompany his article published in the December 2014 issue of SILICON CHIP. The program is called "WEBServer.bas" and can be downloaded for free from siliconchip.com.au/Shop/6/2890

You'll also find that Geoff Graham's article in the December 2014 issue has a listing of the main AT commands needed to communicate with the ESP-01/ESP8266 (page 33, www.siliconchip.com.au/Article/8194).

With an Arduino Mega

As mentioned earlier, the easiest Arduino to connect with the ESP-01 module is the Mega. It's especially easy if you use a WiFi shield like the Freetronics ESP1SH to interface between the two, as shown in the adjacent photo.

The ESP1SH shield makes most of the connections between the ESP-01 and the Arduino Mega, when you plug it in.

The only additional connections you need to make are between the level translated TX and RX lines of the ESP-01 (the uppermost and lowermost rows of pins on the shield's 8x3 programming header) and the IO19/RX1 and IO18/TX1 pins of the Arduino Mega.

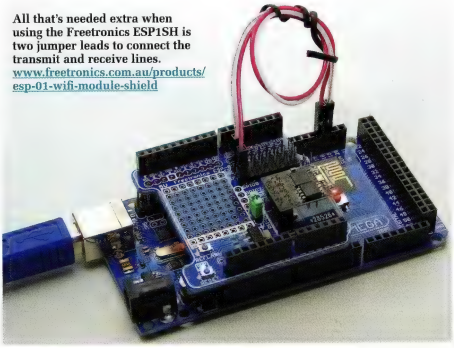
As shown in the photo below and in Fig.4, these added connections are made by short male-to-female jumper leads.

Just remember to remove the jumper shunts which come with the ESP1SH shield, because these can only be used to connect the ESP-01's TX and RX lines to the Mega's IO0/RX0 and IO1/TX0 hardware UART (or to pins IO2-IO7 for using a software serial port).

The jumper lead from one of the uppermost TX pins of the shield's 8x3 header needs to be connected to the Mega's IO19/RX1 socket (blue lead in Fig.4), while the lowermost RX pins on the header should be connected to the Mega's IO18/TX1 socket (red lead in Fig.4). If you get these two connections swapped, your Mega won't be able to communicate with the ESP-01 module.

Programming the Mega for WiFi communication via the ESP-01 is fairly easy. You'll find quite a few Arduino sketches on the web which illustrate how you can use the ESP8266, and there's also a WiFi Library available on the main Arduino website (see www.arduino.cc/en/Reference/Libraries).

To get you started, I've adapted a simple pass-through sketch that I found on one of the websites so that it's capable of running straight away on the Mega/ESP1SH/ESP-01 setup. The sketch makes the Mega behave as a relay station or mirror between



All that's needed extra when using the Freetronics ESP1SH is two jumper leads to connect the transmit and receive lines. www.freetronics.com.au/products/esp-01-wifi-module-shield

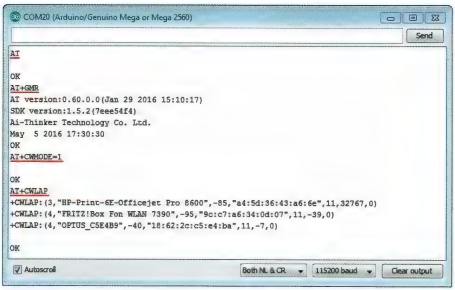


Fig.6: the sample serial passthrough program running on an Arduino Mega. This program merely repeats data to and from the ESP-01 module.

your computer and the ESP-01 and its ESP8266.

So any AT commands sent from your computer via the Arduino IDE's Serial Monitor utility are relayed to the ESP8266, and any responses from the ESP8266 are relayed back to the IDE's Serial Monitor. This makes it easy to try sending various AT commands to the ESP-01 and to see its responses.

The sketch is listed at the end of this section and you can also download it from the SILICON CHIP website.

The screen grab shown in Fig.6 shows how this works. The lines underlined in red are those with the AT commands sent to the ESP-01/ESP8266, while those without any underlining show the responses coming back from it. The first AT command is basically just an enquiry to see if the ESP8266 is awake, with it returning OK if it is.

Similarly, the command AT+GMR resets the ESP8266 and also gets it to respond with information concerning its firmware.

Then the command AT+CWMODE=1 directs the ESP8266 to assume WiFi client mode, as opposed to access point mode (mode 2) or client/access point mode (mode 3).

The additional command shown in Fig.6 is AT+CWLAP which asks the ESP8266 to list any WiFi access points currently available within its range. Of the three lines you can see in Fig.6, the last line corresponds to my office network router, while the other two are routers or peripherals in nearby homes.

The other point to note from Fig.6 is that the Arduino Mega I was using at the time had been allocated to virtual COM port 20 (top left), while the IDE Serial Monitor was communicating with the Mega and ESP8266 at 115,200 baud (bps).

Why not try programming the ESP-01 WiFi module yourself?

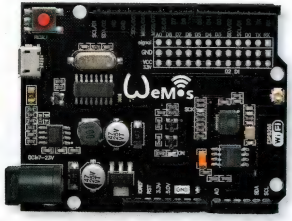
```
// Sample program from Fig.6.
void setup() {
  Serial.begin(115200);
  Serial1.begin(115200);
}
void loop() {
  if (Serial.available())
    Serial1.write(Serial.read());
  if (Serial1.available())
    Serial.write(Serial1.read());
}
```

Loading your own code onto the ESP8266

If you do this, you will lose the AT command set capabilities, since these are provided by the default code loaded into the ESP8266 processor. But it does allow the ESP-01 to become an independent module without the need for many external components.

The best demonstration of this is in our NTP Clock project article on page 58, where we turned an ESP-01 into a device which pretends to be a GPS module, supplying NMEA data from its serial port and a 1pps signal but it actually gets the time, date and location data from NTP and location servers on the internet. This allows you to use a GPS-synchronised clock in a location where a GPS signal is not available.

So we won't go into great detail about how to program the ESP8266 yourself here, as you can refer to that article on page 60 and examine its source code (which can be downloaded from the SILICON CHIP website) to see how it works. SC



The WeMos D1 R2, which is based around the ESP8266, was used in the Water Tank Level Meter project (Feb 18).

Links for using the ESP-01/ESP8266:

https://espressif.com
www.siliconchip.com.au/link/aaj6
https://forum.arduino.cc/index.php?board=11.0
http://bbs.espressif.com
www.electrodragon.com/w/Wi07c
www.siliconchip.com.au/link/aaj7
www.sparkfun.com/products/13678
https://en.wikipedia.org/wiki/ESP8266
www.siliconchip.com.au/link/aaj8
https://github.com/espressif
https://github.com/esp8266/Arduino
https://github.com/tttapa/ESP8266
https://github.com/acrobotic/Ai_Docs
https://github.com/espressif/esp8266_mp3_decoder/

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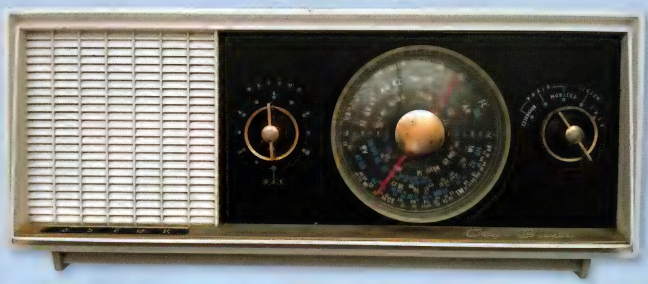
Vintage Radio

By Ian Batty

Astor M2 Cry-baby



a radio, intercom and baby monitor all in one

You might think that baby monitors are a fairly recent innovation but this battery-powered solid-state mantel radio from Astor incorporated an intercom and baby monitor in a design from 1962 – 56 years ago!

This mantel radio looks similar to the Astor M5 and M6 mantel sets that I wrote up in the September 2016 issue (www.siliconchip.com.au/Article/10149). Those mains-powered sets had Class-A audio output stages. At the time, I'd pondered the design brief but supposed that mains sets could easily support the power drain penalty of Class-A.

I did wonder about a battery version and assumed it would need to use the more complex (and thus more costly) Class-B design for battery economy. The 1962 M2 does indeed do this. The Class-B output stage gives an overall drain of around 10mA, meaning that the original Eveready 276-P carbon-zinc battery would last for some 150 hours of use.

As well as the M5/M6's radio function, a remote speaker connected to the M2 allows baby monitoring, playing radio programs at the remote speaker, or conventional "half-duplex" intercom operation. Being able to use the extension speaker for the radio program would be a useful feature even today.

We usually think of loudspeakers as output transducers but (like many electromechanical devices), we can capitalise on their reciprocal nature and use them as microphones. This is what the M2 does with its remote speaker, using it either as a speaker or with a suitable step-up transformer, as a microphone.

I was offered this set for review by a fellow member of the Historical Radio Society of Australia (HRSA), whom I have credited at the end of this article.

Appearance and controls

The cabinet of the Astor M2 is very similar to that of the previously-reviewed M5 and has the same hand-span dial for tuning and a 4-inch speaker on the left-hand side of the front panel.

The set retailed for £37.16s with the case and external speaker presented in a variety of different colours such as cherry red, yellow, brown etc.

The major difference is a 5-position function switch on the right-hand side of the panel, while the volume control-cum-power switch is on the left-hand side. The monitor speaker is in a black circular housing with no styling similarity to the radio.

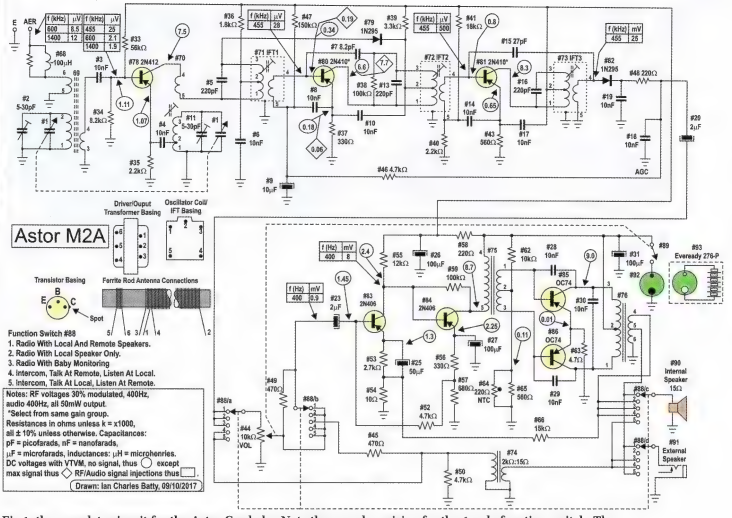


Fig.1: the complete circuit for the Astor Cry-baby. Note the complex wiring for the 4-pole function switch. The loudspeaker was connected via a step-up transformer (#74) when it was being used as a baby monitor.

Position 1 of the function switch simply parallels the monitor speaker with the set's internal speaker, so it operates as an extension to play the received program. Position 2 switches off the monitor speaker.

Position 3 adds remote (baby) monitoring to the radio function but with the remote input at full gain while the radio program is subject to the volume control setting. This would be ideal for baby monitoring; you'd be alerted to anything happening in the nursery while listening to the radio or you could turn the radio down while still monitoring your infant.

Position 4 is a simple intercom working from remote speaker to the set while position 5 reverses the conversation, going from set to monitor.

Just as an aside, if you have one of these sets, make sure that the remote speaker is reasonably remote before switching to position 3: insufficient separation will result in very loud acoustic feedback.

Construction

Like the Astor M5 & M6, the M2 uses a single-sided phenolic PCB mounted behind the plastic front panel and anchored by the volume pot and function switch's shafts, and by two screws; there is no metal chassis.

The only unusual component is the 3.5mm external speaker jack mounted in the rear of the case, and connected to pins on the circuit board by fly leads.

Like the M5/6, tuning knob removal requires gently prising off the gold dress cap in the centre of the dial, undoing the three small screws and securing ring that hold the tuning knob on, then (for circuit board removal), undoing two screws in the tuning boss and sliding it off the gang's shaft.

The set provides for external Aerial and Earth connections to improve reception in fringe areas. As with the M5 model, these "hide" under the set and connect via the two bottom case screws.

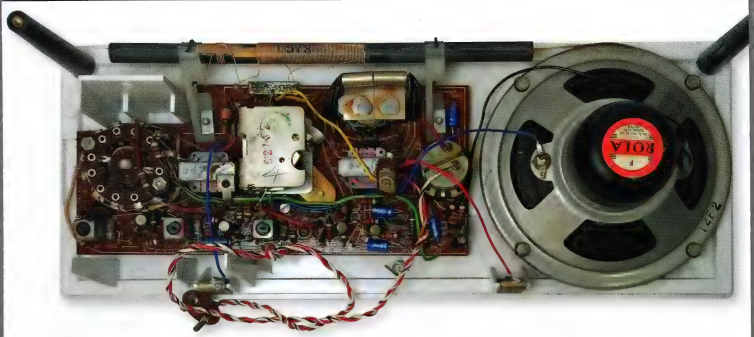
While such connections are always welcome, you'd need to be a long way from the station before this sensitive set needed external assistance.

Fig.1 shows the full circuit and as with other Astor radios, each component has a simple "hash" number. All the transistors are PNP germanium types while the two diodes are also germanium.

However, the battery supply is unconventional, with positive Earth and the circuit has been drawn to show conventional flow from positive to negative, "up the page".

A comparison with the circuit of the Astor M5 featured in the September 2016 issue shows that it is quite similar to that of the M2 model, with the exception of the M2's Class-B audio output amplifier; more correctly termed "Class-AB" because the output transistors do have a small bias to provide quiescent current.

The self-oscillating converter #78, a 2N412, uses collector-emitter feedback with the incoming RF signal applied



The large rotary switch for the function control is on the left hand side of the PCB. The two output transistors are fitted with flag heatsinks which have been soldered to the frame of the output transformer. This photo was taken after replacing numerous electrolytic capacitors.

to the base of the converter (from the ferrite antenna via 10nF capacitor #3). Like almost all such converters, no AGC is applied to this stage.

The tuning gang uses a cut plate oscillator section, so there is no padder capacitor.

The converter feeds through oscillator coil #70's primary to the primary of first IF transformer #71. Its tuned, tapped primary couples to the untuned, untapped secondary.

The first IF amplifier (#80), a 2N410, gets its bias via a 150kΩ resistor (#47) connected to the +9V supply. It is neutralised via an 8.2pF capacitor. Its output goes to the second IF transformer's tuned, tapped primary and its untuned, untapped secondary feeds the second IF amplifier, another 2N410 (#81).

Astor recommended that both IF transistors are picked from the same gain group.

The 1st IF amplifier has AGC applied from the 1N295 detector diode (#82) via a 4.7kΩ resistor (#46). This directly controls the amplifier's gain, and brings AGC extension diode #79, another 1N295, into action with stronger signals.

It's the conventional "Mullard" design, allowing the set to respond to varying signal strengths with a near-constant output level.

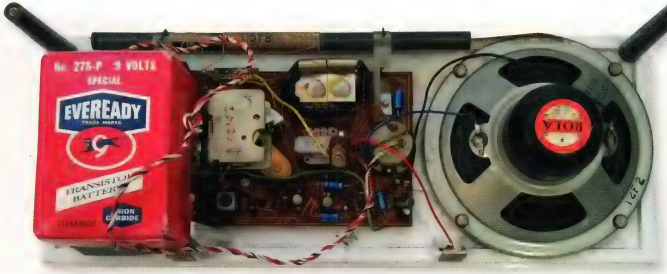
The 2nd IF amplifier is neutralised via a 27pF capacitor (#15). Its value is some three times that of #7, necessary since #15 is fed from the IFT's secondary rather than the primary as with the 1st IF amplifier's #7.

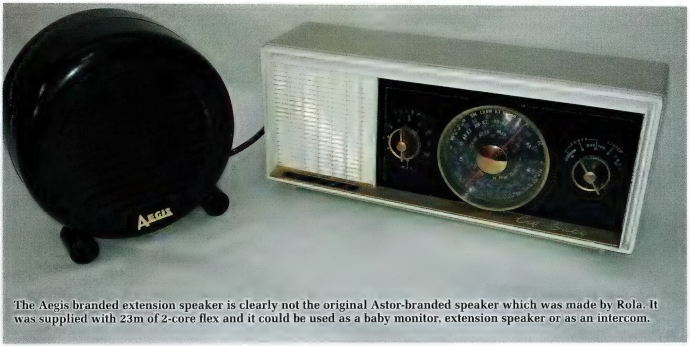
As well as providing the AGC signal, diode #82 provides the demodulated audio signal which is filtered by two 10nF capacitors (#18 and #19) and a 220Ω resistor (#48).

The recovered audio signal is fed to the 10kΩ volume control via a 2µF capacitor and a section of the 4-pole function switch wiring when set the "radio" position.

Audio stages

The audio section of the M2 radio comprises three stages, with the first two 2N406 audio transistors, #83 and #84, operating in a high-gain, direct-





The Aegis branded extension speaker is clearly not the original Astor-branded speaker which was made by Rola. It was supplied with 23m of 2-core flex and it could be used as a baby monitor, extension speaker or as an intercom.

coupled configuration and with DC feedback applied from #84's emitter to #83's base, with the actual voltage picked off from the 330Ω/680Ω (#56/#57) voltage divider. Some local negative feedback is applied across driver transistor #84 via 100kΩ resistor #59.

Both the emitter circuits are bypassed for audio, with transistor #83 having a 10Ω resistor (#54) allowing overall AC feedback to be applied from the speaker output via a 15kΩ resistor (#66).

Transistor #84 feeds the primary of driver transformer #75 and its centre-tapped secondary feeds the two output transistors, #85 and #86. These two OC74s drive the output transformer in push-pull fashion.

They are fitted with flag heatsinks soldered to the frame of the output transformer, giving a large thermal mass to help keep transistor junctions at a constant temperature.

The bias for the output transistors is derived from a voltage divider comprising resistors #62 (10kΩ) and #65 (560Ω) combined with a negative temperature coefficient (NTC) thermistor (#64, 220Ω) to give temperature compensation.

It's the usual arrangement whereby the thermistor reduces bias at higher temperatures to prevent excessive current in the output stage.

This bias network cannot compensate for falling battery voltage and nor can the bias be optimised for individual transistors. This is borne out by the small amount of crossover distortion present even at full battery voltage.

Local feedback is provided by 10nF capacitors #28 and #29 from the collectors to the bases of the output transistors, with further treble cut provided by 10nF capacitor #30.

Monitoring and intercom

Position 3 of the function switch sees a 470Ω resistor (#49) in series between the volume pot's wiper and audio input, with #88/b also connecting a 470Ω resistor (#45) to the audio input via the 2µF capacitor to the base of transistor #83.

This allows audio from the external speaker (operating as a microphone, stepped up by 2kΩ:15Ω matching transformer #74) to be passively mixed with the audio coming via the volume control.

Thus, while it's possible to adjust the level of the radio program, audio from the remote speaker is conveyed at maximum gain.

Position 4 of the function switch removes the radio program but connects to the matching transformer's secondary and conveys its signal to the volume control, while #88/b shorts out resistor #49 to deliver the full signal to the audio amplifier. The set is now a conventional intercom in the "listen" position.

Signal direction, from the external speaker to the internal speaker, is controlled by #88/c conveying the amplifier's output to the internal speaker, and #88/d connecting the external speaker to the input of matching transformer #74.

Position 5 selects "talk" operation. Switch #88/c connects the internal speaker to matching transformer #74 to allow the internal speaker to act as a microphone, while #88/d sends audio output to the external speaker.

Fixing it up

As presented to me, the M2 needed only a light clean and polish to make it sparkle but electrically it was dead. However, my Local Oscillator test brought out that "swishing" sound from my bench radio, so it looked like an audio problem.

Homing in on and replacing electrolytic coupling capacitors #20 and #23 brought immediate results. For good measure, I replaced bypass caps #9, #26 and #31, and got improved performance with emitter bypasses #25 and #27.

Poor quality manufacture? Well, the set had probably been sitting unused for some decades and it's too much to expect the chemically-formed dielectric to persist for so long with no refreshing.

I did try reforming the capacitors but with no success. I'm also pessimistic about the long-term stability of such old components anyway.

If you're having difficulty getting axial-lead electrolytic capacitors, both low-voltage (transistor radios,

valve cathode bypasses) and high-voltage (valve power supplies) types are available from local surplus stores and online.

A tip though: chatting with one local store revealed that axial electrolytics are getting harder to find. I found a range of axial electrolytics at Rockby Electronics in Melbourne. You might like to check out their online catalog.

How good is it?

The Astor M2 is right up there with the best of the alloyed-junction germanium designs. Its sensitivity is aided by the high-gain, three-stage audio section.

For 50mW output, it needed around 45µV/m at 600kHz and 35µV/m at 1400kHz, but at signal-to-noise (S/N) ratios of only -7dB and -10dB, respectively. For the more usual S/N value of -20dB, the equivalent signals were 90µV/m at 600kHz and 65µV/m at 1400kHz.

At the antenna terminal, it needed only 8.5µV at 600kHz and 12µV at 1400kHz, for S/N ratios of -9dB and -10dB. For the usual -20dB ratios: 16µV and 21µV, respectively.

IF bandwidth is ±1.5kHz at -3dB down and ±24kHz at -60dB down. AGC allows some 6dB rise in audio for a 50dB signal increase. I did finally get it to overload at around 200mV/m; an exceptional performance.

Audio response from antenna to speaker was 50Hz to 1500Hz, with a peak at about 80Hz. From volume control to speaker, it's 65Hz to 7800Hz.

From the monitoring speaker input, it's around 135Hz to 8500Hz, with a 7dB peak at 5kHz. This may be due to input transformer resonance but it would help compensate for the monitor speaker's expected weak high-frequency response.

At 50mW, audio distortion was commendably low, at only 0.8% but it rose to 1.5% at 10mW, with discernible crossover distortion. This confirms the limitations of non-adjustable bias circuits.

It went into clipping at 400mW, with 10% distortion at 500mW. At a low battery voltage of 4.5V, it clips at 80mW, with around 5% THD at 50mW, noticeably crossover distortion.

As a radio, it's great. And for its special features, it's equally so. The remote speaker input gives 50mW out with only 250µV of audio input at full volume.

Women's Weekly, 18th July, 1962: https://trove.nla.gov.au/aww/read/222697

This is certainly adequate to pick up sounds from the monitor speaker, even with "house-length" runs of common speaker cable. In fact, the radio was supplied with 75 feet (23m) of 2-core flex for this purpose.

Whether used as a portable radio, nursery monitor or as an ordinary intercom, the audio section's high sensitivity and generous audio output mean that it easily fills the bill.

Would I Buy One?

That's tempting but I'd like to get an M2 with the original Astor speaker. While the substitute Aegis monitor works just fine, there's no substitute for the genuine article (actually made by Rola).

If you happen to have either the complete radio-and-speaker kit that you'd like to move on, or even just the speaker, please drop Graham or me a line via SILICON CHIP ([02]9939-3295 or silicon@siliconchip.com.au).

Acknowledgement:

Special thanks to Associate Professor (retired) Graham Parslow of the HRSA, for this interesting example of fine Australian engineering and manufacture.

Further reading

You will find the circuit and service info on Kevin Chant's excellent site at www.kevinchant.com/uploads/7/1/0/8/7108231/m2a.pdf SC

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Is WiFi Water Tank Level Meter suitable for drinking water?

Can you confirm if the water level/pressure sensor that you sell for the WiFi Water Tank Level Meter (Cat SC4283) is safe to be used in tanks for drinking water? My understanding is that it needs to be "Food Grade" to be suitable. (D. B., Glenn Forest, WA)

● There is no indication in any of the specifications supplied to us that the sensors are food grade.

The sensor housing is made of stainless steel but we don't know what kind of plastic insulation is used on the wire or whether there may be any potentially toxic materials inside the sensor housing. The sensors are most suitable for rainwater or "grey" water, used for watering plants, flushing toilets and so on.

TV channel interference at night

I have a really perplexing problem regarding digital TV reception, specifically the stations on 219.500MHz (Network Ten). During daylight hours, all networks are at 100% strength and quality.

Come night, say from 7:30pm, all stations on this frequency break up, pixelate and are then, for want of a better word, gone. Signal strength still reads 100% but the bit error rate is maximum. That results in no picture or sound.

Two networks 7MHz either side of 219.500MHz show no sign of any problems (Nine and ABC). On talkback radio this weekend, I heard one of those "techie" guys explain that the new LED globes can interfere with digital TV reception.

Have you heard of this problem? We are so frustrated that we now have a VHF-only antenna in the hope that it may be a quick fix. Unfortunately, it didn't help. (D. McC., Allawah, NSW)

● We would be surprised if any LED lamps would cause interference at those high frequencies. The problem is more likely to be related to some local source which is more active at night, perhaps related to internet use from the NBN or ADSL.

Do any of your neighbours have the same problem? If not, the source may in your own household. Is a family member always on the 'net at night?

Trouble aligning Super-7 AM Radio

I have just built the Super-7 AM Radio (November & December 2017; siliconchip.com.au/Series/321) and am having trouble getting it working properly.

The stations are too far towards the high-frequency end of the dial and when I adjust the oscillator coil to correct this, they disappear altogether.

I really should have a signal generator and oscilloscope at hand but managed without them when I constructed the RTV&H Transporta 7 in 1964 (it still works, by the way).

During my deliberations, I looked at Jaycar's data for the ferrite aerial coil and the tuning condenser. The aerial coil inductance is stated as 200µH and the tuner's aerial gang capacitance as 141.6pF, although Jaycar advertises it as 160pF. My calculation of the aerial tuned circuit resonant frequency is 890kHz with the tuner at 160pF and 946kHz at 141.6pF.

Given that the frequency is supposed to range down to 530kHz or thereabouts, I wonder whether there is a basic design problem or whether I have missed something. Your advice would be much appreciated. (R. H., Bronte, NSW)

● The ferrite rod, coil and tuning capacitor are designed to suit the AM broadcast band. The inductance can be changed markedly by moving the coil on the ferrite rod.

Also, the tuning gang capacitance is affected by the trimmer at the back of the capacitor gang. Getting these correct for alignment can be a slow procedure if these are initially way off value.

If you can carefully follow the adjustment procedure, you should be able to receive the bottom end of the band. We were able to pick up the Sydney ABC stations at 702kHz and 576kHz with our prototype.

Continuing confusion over "MMC" capacitors

In regards to the January 2013 "Champion" amplifier (www.siliconchip.com.au/Article/1301). In the Parts List on page 26, some of the capacitors are specified as 100nF MMC.

What does MMC refer to? I have not seen it referred to in the Jaycar, Altronics, element14 or RS catalogs. I do see MKT, tantalum, monolithic, polyester and ceramic capacitors. Are any of these equivalent to MMC? (A. P., Manapouri, NZ)

● "MMC" stands for Monolithic Multilayer Ceramic. It is now an outdated term and we are trying to avoid using it. You still see it occasionally on part supplier websites and elsewhere.

"Monolithic" describes one type of multi-layer ceramic construction. It is not really relevant to most applications. As a result, you now mainly see capacitors described as "multilayer ceramic", sometimes abbreviated to MLC or MLCC. They are basically equivalent to monolithic/MMC capacitors.

Sourcing a transformer for the SC200

An EPE reader is having trouble finding a suitable mains transformer for the SC200 Amplifier module (January-March 2017; siliconchip.com.au/Series/308).

We can't find a 40-0-40 + 15-0-15 transformer anywhere. The dual secondaries are the problem. Jaycar and Altronics don't have them. Do you have an alternative source? Also, what is the part number for ferrite bead FB1? (M. P., Wimborne, UK)

● The transformer used originally was the Altronics MC5540 which has

now been discontinued, along with the amplifier kits which included that transformer.

The easiest solution is to use two transformers: one 300VA 40-0-40 transformer and a 20-30VA 15-0-15 transformer like Jaycar MT2086 or Altronics M4915B. The primaries of the two transformers should be wired in parallel.

Arguably this is superior to a single transformer since the 300VA transformer is then tasked with only supplying the power amplifiers, so it will be able to supply slightly more peak current. It should also make chassis layout and wiring easier.

The ferrite bead type isn't critical; Laird HZ1206E152R-10 would be a good choice.

Question about unused op amp

Regarding the WiFi Water Tank Level Meter circuit on page 22 of the February 2018 issue (siliconchip.com.au/Article/10963), I don't understand the function of the IC1a voltage follower. You don't appear to discuss IC1a in the text. Thanks for such a great magazine with fantastic project presentation. (S. E., Scullin, ACT)

- IC1a is the unused half of the dual op amp. Only IC1b is required but IC1a needs to have its inputs connected to voltage levels within its common mode range. Making it a voltage follower is a simple way to achieve this.

Since it's an LM358, we could have connected pin 3 to pin 4 instead (ground) but some op amps will misbehave with the inputs tied to ground so this is a safer general configuration for unused op amp stages.

CDI wanted for Honda CBR250

I am looking for information about some of your Capacitor Discharge Ignition designs. I have a 4-cylinder Honda CBR250 motorcycle running two pulser coils that are mounted about 30° apart.

I am wondering if you have a kit that would work in my application. I'd like to be able to program the advance curve; the original CDI only references RPM for its mapping. (J. L., via email)

- We have published a High-Energy Multi-spark CDI design (December 2014 & January 2015; siliconchip.com.au/Series/279), a Programmable Ignition system (March-June 2007; siliconchip.com.au/Series/56), plus a standard High-energy Ignition system (November-December 2012; siliconchip.com.au/Series/18).

For irregularly spaced triggers such as in your engine, it would require at least two ignition systems, one for the first trigger and another for the trigger 30° apart. The size of these ignitions may not suit a motorcycle, especially if you include the programmable ignition ahead of the CDI unit.

Resistors for Theremin and kit availability

I am building the Theremin as

Could the RapidBrake have been designed without relays?

I have three questions:

Could the RapidBrake (July-August 2017; siliconchip.com.au/Series/314) have been designed as an OBD-II dongle and as such not need relays? I am guessing the brake lights are accessible via the OBD-II bus.

Secondly, regarding your Arduino Data Logger project (August-September 2017; siliconchip.com.au/Series/316), I am interested in building it to store weather data but how can I log rain (tipping bucket) and wind speed/direction?

Would I be best looking at a different design or can yours be modified to do it?

Lastly, with the "El Cheapo" modules you have been informing us about, have you considered the BME280 or BME680 barometric pressure modules?

They are remarkable for their prices and easy to use with an Arduino. (P. R., Bribie Island, Qld)

- While it's probably possible to monitor brake light status on some vehicles via the OBD-II bus, we are not aware of any (standard) way to activate the brake lights over that bus.

Indeed, on many vehicles, even those new enough to have an OBD-II connector, the brake lights are still activated by a physical switch in the pedal mechanism.

Even if some modern vehicles do have the brake lights under control of the body computer and you could somehow command it to activate them via the OBD-II interface, that would rule out its use on any vehicles lacking this capability and all vehicles that pre-date OBD-II.

It became mandatory in 2005-2007, depending on vehicle type, although some vehicles dating back to the late 1990s have it.

Since our Data Logger is based on the Arduino and the source code can be downloaded, there's nothing to stop constructors from adding the ability to measure rainfall, wind speed and direction.

We provided sample instructions on how to interface extra sensors; it wouldn't be exactly the same but that should serve as a general guide to the steps required.

The difficulty with rainfall measurement using a tipping bucket is that to save power, our Data Logger puts the micro into sleep mode much of the time and thus it could miss pulses during this period.

You can arrange for the micro to wake up when the level changes on a specific pin and this is what we would be tempted to do, as you could keep the power savings without missing these pulses, which will not normally occur frequently anyway.

For wind speed and direction, it really depends on the type of wind speed sensor you are using.

Wind speed will probably be based on counting pulses over a given period and so the above also applies, except that you will also need to divide the number of pulses by the timespan they are recorded over to calculate the speed.

Determination of wind direction may require a few digital inputs or one analog input. In short, it should be possible to add these features but may require some coding skill.

Finally, the BME680 looks like a good chip but the cheapest module we can find is around $50 which doesn't exactly fit into the "El Cheapo" category.

described in January 2018 issue of Silicon Chip magazine (siliconchip.com.au/Article/10931).

My question is: are 5% tolerance resistors acceptable for this project? The reason for this question is that I have already purchased and fitted 5% resistors before I realised that 1% resistors were specified. (P. I., Alawa, NT)

● Yes, 5% resistors should work in this project. By the way, we believe that Jaycar will be releasing a kit for this Theremin fairly soon.

Directionality in audio cables is nonsense

Recently, whilst dining with a friend of mine, we got to discussing audio equipment and the difference in audio cables. He explained to me that the high-quality audio cables he purchased some time ago become noticeably better over time, due to burn-in, or break-in. He would not accept that most of the information he has read is far-fetched sales blurb.

I mentioned the importance of such things as shielding and cable losses etc, but I was not a believer in the break-in theory. He tried to convince me that it is true and he read it on the experts' websites, such as Nordost – see the FAQs at www.nordost.com/faqs.php

In the FAQ "How can cables be directional?" They explain that during the break-in period cables acquire directionality – "small impurities in the conductor act as diodes allowing signal flow to be better in one direction over time. This effect is also called quantum tunneling,".

Other related FAQs are also an interesting read. Would you care to share an educated opinion on this mumbo-jumbo? (T. C., via email)

● Sadly, this fraudulent nonsense is still being pushed by marketing companies. As you say, it **is** mumbo-jumbo.

Cables are not directional, nor is there any way they could be made directional without introducing some form of non-linearity. After all, audio signals are AC, so current flow in the cable is constantly changing direction.

Therefore, if such a non-linearity was present, it would cause audible distortion. Small impurities in copper or other conductors do not act as diodes. If they did, it would possible to measure the diode effect.

In fact, it is quite simple to measure if there is any difference in conductance (the reciprocal of resistance) in a cable in both directions. Just use your multimeter (set to ohms) and measure the resistance in both directions of the cable. Apart from tiny variations in contact resistance between repeated measurements, there will be no difference.

Oh, and if the proponents of this effect try to state that the directionality is also present in the dielectric of shielded cables, that is also nonsense and can be refuted by measurements with AC signals.

And nor is there any effect if a polarising voltage is applied to the cable. In any case, external audio cables used in audio systems are not polarised.

That brings up another point. Contact resistance between dissimilar metals **can** cause non-linearity and can be a source of distortion. This applies particularly to cheap spring-loaded terminals on the back of some audio amplifiers and loudspeakers. Ideally, they should be hefty brass screw connections with gold flashing.

And can cables get better over time and do they need any burn-in? Again, this is nonsense. No components improve over time – they all deteriorate and eventually fail, even if it happens after decades of use. Always remember: "Entropy is increasing!"

It is true that the cone resonance of woofer loudspeakers can slightly reduce after an initial period of use, say a couple of hours. But after that, there is no improvement.

Consider that the reduction in cone resonance is due to an increase in compliance of the cone suspension, ie, the roll surround and the central spider which precisely locates the voice coil over the magnet's pole piece.

In other words, the suspension becomes looser. Is this not an initial deterioration in stiffness of the suspension? It is.

We should also state that some RCA cables are cheap-jack, with flimsy connectors and it is better to purchase

Testing relays

Have you published a project or kit to test relays with? Or is there a schematic diagram of one that I could make? (B. V., via email)

● We have not published a relay tester. It is not really practical to design a tester due to the range of relay types available.

Standard relays are relatively easy to test. You will need a power supply to drive the relay coil with the correct voltage. Some relays require 12V DC for the coil, while others can be 5V DC.

Mains operated relays require a 230VAC supply to the coil in order to switch contacts. Take care if testing these as contact with the mains voltage can be lethal.

Relays will operate over a wide range of voltages below the rated coil voltage. See the data for the relay.

Specifications are usually given for the "must operate" (ie, minimum voltage at which the relay is guaranteed to switch on) and the "holding voltage" (voltage below which the relay may switch off again) for the coil.

To test the coil, apply power to it and check that it draws current. You may hear a click as the relay draws the armature to its solenoid.

The relay contacts can be checked using a multimeter. The normally open (NO) contacts should show high resistance (above 1MΩ) between that contact and the common (COM) when the relay coil is not powered but will be low resistance (<1Ω) when closed as power is applied to the relay coil.

For normally closed (NC) contacts, it is the reverse. There will be a low resistance reading when the coil is not powered and high resistance when the coil is energised.

Relay contacts may become pitted with use and so contact testing can be more effective by applying current through the contacts to check contact resistance under load.

Latching relays are different and the data for the particular relay will need to be checked for setting and resetting the contacts.

Some have one coil, where the applied polarity is reversed to switch the relay on and off, while other relays have two coils for operation, one to switch on and one to switch off.

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Looking for a specialised component to build that latest and greatest Silicon Chip project? Maybe it's the PCB you're after? Or a pre-programmed micro? Or some other hard-to-get "bit"? The chances are they are available direct from the Silicon Chip Online Shop.

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✔ **MAIL** (24 hours, 7 days): PO Box 139, Collaroy NSW 2097. Clearly tell us what you want and include your contact and credit card details

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PRE-PROGRAMMED MICROS

All micros are just $15.00 each + $10 p&p per order#

As a service to readers, the Silicon Chip Online Shop stocks micros *used in new projects* (from 2012 on) and some selected older projects – pre-programmed and ready to fly!

**Some micros from copyrighted and/or contributed projects may not be available.*

PIC12F675-I/P	UHF Remote Switch (Jan09), Ultrasonic Cleaner (Aug10) Ultrasonic Anti-fouling (Sep10), CricketFrog (Jun12), Do Not Disturb (May13) IR-to-UHF Converter (Jul13), UHF-to-IR Converter (Jul13) PC Birdies *2 chips – $15 pair# (Aug13), Driveway Monitor Receiver (July15) Hotel Safe Alarm (Jun16), 50A Battery Charger Controller (Nov16) Kelvin the Cricket (Oct17), Triac-based Mains Motor Speed Controller (Mar18) **Heater Controller (Apr18)**	**PIC16F877A-I/P**	6-Digit GPS Clock (May-Jun09), Lab Digital Pot (Jul10), Semtest (Feb-May12)
		PIC16F2550-I/SP	Batt Capacity Meter (Jun09), Intelligent Fan Controller (Jul10)
		PIC16F4550-I/P	GPS Car Computer (Jan10), GPS Boat Computer (Oct10)
		PIC18LF14K22	Digital Spirit Level (Aug11), G-Force Meter (Nov11)
		PIC32MX795F512H-80I/PT	Maximite (Mar11), miniMaximite (Nov11), Colour Maximite (Sept/Oct12) Touchscreen Audio Recorder (Jun/Jul 14)
PIC12F675-I/P	Courtesy LED Light Delay for Cars (Oct14), Fan Speed Controller (Jan18)	**PIC32MX170F256B-50I/SP**	Micromite Mk2 (Jan15) – *also includes **FREE 47µF tantalum capacitor* Micromite LCD BackPack (either version) (Feb16), GPS Boat Computer (Apr16) Micromite Super Clock (Jul16), Touchscreen Voltage/Current Ref (Oct-Dec16) Micromite LCD BackPack V2 (May17), Deluxe eFuse (Aug17) Micromite DDS for IF Alignment (Sept17)
PIC16F1455-I/P	Microbridge (May17)		
PIC16F1507-I/P	Wideband Oxygen Sensor (Jun-Jul12)		
PIC16F88-E/P	Hi Energy Ignition (Nov/Dec12), Speedo Corrector (Sept13) Auto Headlight Controller (Oct13), 10A 230V Motor Speed Controller (Feb14) Automotive Sensor Modifier (Dec16)	**PIC32MX170F256D-I/SP**	Low Frequency Distortion Analyser (Apr15)
		PIC32MX170F256D-50I/PT	44-pin Micromite Mk2
PIC16F88-I/P	Projector Speed (Apr11), Vox (Jun11), Ultrasonic Water Tank Level (Sep11) Quizzical (Oct11), Ultra LD Preamp (Nov11), 10-Channel Remote Control Receiver (Jun13), Revised 10-Channel Remote Control Receiver (Jul13) Nicad/NiMH Battery Charger (Mar14), Remote Mains Timer (Nov14) Driveway Monitor Transmitter (July15), Fingerprint Scanner (Nov15) MPPT Lighting Charge Controller (Feb16), 50/60Hz Turntable Driver (May16) Cyclic Pump Timer (Sep16), 60V 40A DC Motor Speed Controller (Jan17) Pool Lap Counter (Mar17), Rapidbrake (Jul17)	**PIC32MX250F128B-I/SP**	CPS Tracker (Nov13), Micromite ASCII Video Terminal (Jul14)
		PIC32MX470F512H-I/PT	Stereo Audio Delay/DSP (Nov13), Stereo Echo/Reverb (Feb 14) Digital Effects Unit (Oct14)
		PIC32MX470F512H-120/PT	Micromite PLUS Explore 64 (Aug 16), Micromite Plus LCD BackPack (Nov16)
		PIC32MX470F512L-120/PT	Micromite PLUS Explore 100 (Sep-Oct16)
PIC16LF88-I/P	Garbage Reminder (Jan13), Bellbird (Dec13), GPS Analog Clock Driver (Feb17)	**dsPIC33FJ128GP802-I/SP**	Digital Audio Signal Generator (Mar-May10), Digital Lighting Controller (Oct-Dec10), SportSync (May11), Digital Audio Delay (Dec11) Quizzical (Oct11), Ultra-LD Preamp (Nov11), LED Musicolor (Nov12)
PIC16LF88-I/SO	LED Ladybird (Apr13)	**dsPIC33FJ64MC802-E/P**	Induction Motor Speed Controller (revised) (Aug13)
PIC16LF1709-I/SO	Battery Cal Balancer (Mar16)	**dsPIC33FJ128GP306-I/PT**	CLASSIC DAC (Feb-May 13)

When ordering, be sure to select BOTH the micro required AND the project for which it must be programmed.

SPECIALISED COMPONENTS, HARD-TO-GET BITS, ETC

P&P – $10 Per order#

AM RADIO TRANSMITTER *(MAR 18)*
MC1496P double-balanced mixer IC (DIP-14) **$2.50**

VINTAGE TV A/V MODULATOR *(MAR 18)*
MC1374P A/V modulator IC (DIP-14) **$5.00**
SMK-71K coil former pack **(two required)** **$5.00 ea.**

ALTIMETER/WEATHER STATION *(DEC 17)*
Micromite 2.8-inch LCD BackPack kit programmed for the Altimeter project **$65.00**
GY-68 barometric pressure and temperature sensor module (with BMP180, Cat SC4343) **$5.00**
DHT22 temperature and humidity sensor module (Cat SC4150) **$7.50**
Elecrow 1A/500mA Li-ion/LiPo charger board **(optional**, Cat SC4306) **$15.00**

PARTS FOR THE 6GHz+ TOUCHSCREEN FREQUENCY COUNTER *(OCT 17)*
Explore 100 kit (Cat SC5834; no LCD included) **$69.90**
one ERA-2SM+ & one ADCH-80A+ (Cat SC1167; two packs required) **$15.00/pk.**

DELUXE EFUSE PARTS *(AUG 17)*
IRF9Z34NPBF P-channel mosfets (Cat SC4318) **$4.00 ea.**
BUK7909-75AIE 75V 120A N-channel SenseFet (Cat SC4317) **$7.50 ea.**
LT1490ACN8 dual op amp (Cat SC4319) **$7.50 ea.**

ARDUINO LC METER (CAT SC4273) *(JUN 17)*
One 1% MKP capacitor, 5mm lead spacing **$2.50**

MICROBRIDGE COMPLETE KIT (CAT SC4264) *(MAY 17)*
PCB plus all on-board parts including programmed microcontroller (SMD ceramics for 10µF) **$20.00**

MICROMITE LCD BACKPACK V2 – COMPLETE KIT (CAT SC4237) *(MAY 17)*
includes PCB, programmed micro, touchscreen LCD, laser-cut UB3 lid, mounting hardware, SMD Mosfets for PWM backlight control and all other on-board parts **$70.00**

POOL LAP COUNTER *(MAR 17)*
two 70mm 7-segment high brightness blue displays + logic-level Mosfet (Cat SC4189) **$17.50**
laser-cut blue tinted UB1 lid, 152 x 90 x 3mm (Cat SC4196) **$7.50**

STATIONMASTER (CAT SC4187) *(MAR 17)*
Hard to get parts: DRV8871 IC, SMD 1µF capacitor and 100kΩ potentiometer with detent **$12.50**

ULTRA LOW VOLTAGE LED FLASHER (CAT SC4125) *(FEB 17)*
kit including PCB and all SMD parts, LDR and blue LED **$12.50**

SC200 AMPLIFIER MODULE (CAT SC4140) *(JAN 17)*
hard-to-get parts: Q8-Q16, D2-D4, 150pF/250V capacitor and five SMD resistors **$35.00**

60V 40A DC MOTOR SPEED CONTROLLER (CAT SC4142) *(JAN 17)*
hard-to-get parts: IC2, Q1, Q2 and D1 **$35.00**

VARIOUS MODULES
ESP-01 WiFi Module (Ei Cheap Modules, Part 15, APR18) **$5.00**
WiFi Antennas with U.FL/IPX connectors (Water Tank Level Meter with WiFi, FEB18):
5dBi – **$12.50** – 2dBi (omnidirectional) – **$10.00**
NRF24L01+PA+NA transceiver with SNA connector and antenna (Ei Cheap Project 12, JAN18) **$5.00**
WeMos D1 Arduino-compatible boards with WiFi (SEPT17, FEB18):
ThingSpeak data logger – **$10.00** – **WiFi Tank Level Meter (ext. antenna socket)** – **$15.00**
Geeetech Arduino MP3 shield (Arduino Music Player/Recorder, VS1053, JUL17) **$20.00**
MAX7219 LED controller boards (Ei Cheapo Modules, Part 7, JUN17):
8x8 red SMD/DIP matrix display – **$5.00** – red 8-digit 7-segment display – **$7.50**
AD9833 DDS module (with gain control) (for Micromite DDS, APR17) **$25.00**
AD9833 DDS module (no gain control) (Ei Cheapo Modules, Part 6, APR17) **$15.00**
DP2102 USB-UART bridge **$5.00**
microSD card adaptor (Ei Cheapo Modules, Part 3, JAN17) **$2.50**
DS3231 real-time clock with mounting spacers and screws (Ei Cheapo, Part 1, OCT16) **$5.00**

MICROMITE PLUS EXPLORE 100 COMPLETE KIT (no LCD panel) *(SEP 16)*
(includes PCB, programmed micro and the hard-to-get bits including female headers, USB and microSD sockets, crystal, etc but does not include the LCD panel) (Cat SC3834) **$69.90**

MICROMITE LCD BACKPACK V1 COMPLETE KIT (CAT SC3321) *(FEB 16)*
includes PCB, micro, 2.8-inch touchscreen and includes UB3 lid (clear, matte black or translucent blue). Also specify what project the micro should be programmed for **$65.00**

THESE ARE ONLY THE MOST RECENT MICROS AND SPECIALISED COMPONENTS. FOR THE FULL LIST, SEE www.siliconchip.com.au/shop

All items subject to availability. Prices valid for month of magazine issue only. All prices in Australian dollars and include GST where applicable. # P&P prices are within Australia. O'seas? Please email for a quote

04/18

PRINTED CIRCUIT BOARDS

NOTE: The listings below are for the PCB ONLY. If you want a kit, check our store or contact the kit suppliers advertising in this issue. For unusual projects where kits are not available, some have specialised components available – see the list opposite.

NOTE: not all PCBs are shown here due to space limits but the SILICON CHIP Online Shop has boards going back to 2001 and beyond. For a complete list of available PCBs etc, go to *siliconchip.com.au/shop/8* Prices are PCBs only, NOT COMPLETE KITS!

PRINTED CIRCUIT BOARD TO SUIT PROJECT:	PUBLISHED:	PCB CODE:	Price:
CLASSIC DAC MAIN PCB	APR 2013	01102131	$40.00
CLASSIC DAC FRONT & REAR PANEL PCBs	APR 2013	01102132/3	$30.00
GPS USB TIMEBASE	APR 2013	04104131	$15.00
LED LADYBIRD	APR 2013	08103131	$5.00
CLASSIC-D 12V to ±35V DC/DC CONVERTER	MAY 2013	11104131	$15.00
DO NOT DISTURB	MAY 2013	12104131	$10.00
LF/HF UP-CONVERTER	JUN 2013	07106131	$10.00
10-CHANNEL REMOTE CONTROL RECEIVER	JUN 2013	15106131	$15.00
IR-TO-455MHz UHF TRANSCEIVER	JUN 2013	15106132	$7.50
"LUMP IN COAX" PORTABLE MIXER	JUN 2013	01106131	$15.00
L'IL PULSER MKII TRAIN CONTROLLER	JULY 2013	09107131	$15.00
L'IL PULSER MKII FRONT & REAR PANELS	JULY 2013	09107132/3	$20.00/set
REVISED 10 CHANNEL REMOTE CONTROL RECEIVER	JULY 2013	15106133	$15.00
INFRARED TO UHF CONVERTER	JULY 2013	15107131	$5.00
UHF TO INFRARED CONVERTER	JULY 2013	15107132	$10.00
IPOD CHARGER	AUG 2013	14108131	$5.00
PC BIRDIES	AUG 2013	08104131	$10.00
RF DETECTOR PROBE FOR DMMs	AUG 2013	04107131	$10.00
BATTERY LIFESAVER	SEPT 2013	11108131	$5.00
SPEEDO CORRECTOR	SEPT 2013	05109131	$10.00
SIDRADIO (INTEGRATED SDR) Main PCB	OCT 2013	06109131	$35.00
SIDRADIO (INTEGRATED SDR) Front & Rear Panels	OCT 2013	06109132/3	$25.00/pr
TINY TIM AMPLIFIER (Identical Headphone Amp (Sept'11))	OCT 2013	01309111	$20.00
AUTO CAR HEADLIGHT CONTROLLER	OCT 2013	03111131	$10.00
GPS TRACKER	NOV 2013	05112131	$15.00
STEREO AUDIO DELAY/DSP	NOV 2013	01110131	$15.00
BELLBIRD	DEC 2013	08112131	$10.00
PORTAPAL-D MAIN BOARDS	DEC 2013	01111131-3	$35.00/set
(for CLASSIC-D Amp board and CLASSIC-D DC/DC Converter board – refer above (Nov 2012/May 2013))			
LED Party Strobe (also suits Hot Wire Cutter [Dec 2010])	JAN 2014	16101141	$7.50
Bass Extender Mk2	JAN 2014	01112131	$15.00
L'il Pulser Mk2 Revised	JAN 2014	09107134	$15.00
10A 230VAC MOTOR SPEED CONTROLLER	FEB 2014	10102141	$12.50
NICAD/NIMH BURP CHARGER	MAR 2014	14103141	$15.00
RUBIDIUM FREQ. STANDARD BREAKOUT BOARD	APR 2014	04105141	$10.00
USB/RS232C ADAPTOR	APR 2014	07103141	$5.00
MAINS FAN SPEED CONTROLLER	MAY 2014	10104141	$10.00
RGB LED STRIP DRIVER	MAY 2014	16105141	$10.00
HYBRID BENCH SUPPLY	MAY 2014	18104141	$20.00
2-WAY PASSIVE LOUDSPEAKER CROSSOVER	JUN 2014	01205141	$20.00
TOUCHSCREEN AUDIO RECORDER	JUL 2014	01105141	$12.50
THRESHOLD VOLTAGE SWITCH	JUL 2014	99106141	$10.00
MICROMITE ASCII VIDEO TERMINAL	JUL 2014	24107141	$7.50
FREQUENCY COUNTER ADD-ON	JUL 2014	04105141a/b	$15.00
TEMPMASTER MK3	AUG 2014	21108141	$15.00
44-PIN MICROMITE	AUG 2014	24108141	$5.00
OPTO-THEREMIN MAIN BOARD	SEP 2014	23108141	$15.00
OPTO-THEREMIN PROXIMITY SENSOR BOARD	SEP 2014	23108142	$5.00
ACTIVE DIFFERENTIAL PROBE BOARDS	SEP 2014	04107141/2	$10.00/set
MINI-D AMPLIFIER	SEP 2014	01110141	$8.00
COURTESY LIGHT DELAY	OCT 2014	05109141	$7.50
DIRECT INJECTION (D-I) BOX	OCT 2014	23109141	$5.00
DIGITAL EFFECTS UNIT	OCT 2014	01110131	$15.00
DUAL PHANTOM POWER SUPPLY	NOV 2014	18112141	$10.00
REMOTE MAINS TIMER	NOV 2014	19112141	$10.00
REMOTE MAINS TIMER PANEL/LID (BLUE)	NOV 2014	19112142	$15.00
ONE-CHIP AMPLIFIER	NOV 2014	01109141	$5.00
TDR DONGLE	DEC 2014	04112141	$5.00
MULTISPARK CDI FOR PERFORMANCE VEHICLES	DEC 2014	05112141	$10.00
CURRAWONG STEREO VALVE AMPLIFIER MAIN BOARD	DEC 2014	01111141	$50.00
CURRAWONG REMOTE CONTROL BOARD	DEC 2014	01111142	$5.00
CURRAWONG FRONT & REAR PANELS	DEC 2014	01111142/3	$30.00/set
CURRAWONG CLEAR ACRYLIC COVER	JAN 2015	SC2892	$25.00
ISOLATED HIGH VOLTAGE PROBE	JAN 2015	04108141	$10.00
SPARK ENERGY METER MAIN BOARD	FEB/MAR 2015	05101151	$10.00
SPARK ENERGY ZENER BOARD	FEB/MAR 2015	05101152	$10.00
SPARK ENERGY METER CALIBRATOR BOARD	FEB/MAR 2015	05101153	$5.00
APPLIANCE INSULATION TESTER	APR 2015	04103151	$10.00
APPLIANCE INSULATION TESTER FRONT PANEL	APR 2015	04103152	$10.00
LOW-FREQUENCY DISTORTION ANALYSER	APR 2015	04104151	$5.00
APPLIANCE EARTH LEAKAGE TESTER PCBs (2)	MAY 2015	04203151/2	$15.00
APPLIANCE EARTH LEAKAGE TESTER LID/PANEL	MAY 2015	04203153	$15.00
BALANCED INPUT ATTENUATOR MAIN PCB	MAY 2015	04105151	$15.00
BALANCED INPUT ATTENUATOR FRONT & REAR PANELS	MAY 2015	04105152/3	$20.00
4-OUTPUT UNIVERSAL ADJUSTABLE REGULATOR	MAY 2015	18105151	$5.00
SIGNAL INJECTOR & TRACER	JUNE 2015	04106151	$7.50
PASSIVE RF PROBE	JUNE 2015	04106152	$2.50
SIGNAL INJECTOR & TRACER SHIELD	JUNE 2015	04106153	$5.00
BAD VIBES INFRASOUND SNOOPER	JUNE 2015	04104151	$5.00
CHAMPION + PRE-CHAMPION	JULY 2015	01109121/2	$7.50
DRIVEWAY MONITOR TRANSMITTER PCB	JULY 2015	15105151	$10.00
DRIVEWAY MONITOR RECEIVER PCB	JULY 2015	15105152	$5.00

PRINTED CIRCUIT BOARD TO SUIT PROJECT:	PUBLISHED:	PCB CODE:	Price:
MINI USB SWITCHMODE REGULATOR	JULY 2015	18107151	$2.50
VOLTAGE/RESISTANCE/CURRENT REFERENCE	AUG 2015	04108151	$2.50
LED PARTY STROBE MK2	AUG 2015	16101141	$7.50
ULTRA-LD MK4 200W AMPLIFIER MODULE	SEP 2015	01107151	$15.00
9-CHANNEL REMOTE CONTROL RECEIVER	SEP 2015	15108151	$15.00
MINI USB SWITCHMODE REGULATOR MK2	SEP 2015	18107152	$2.50
2-WAY PASSIVE LOUDSPEAKER CROSSOVER	OCT 2015	01205141	$20.00
ULTRA LD AMPLIFIER POWER SUPPLY	OCT 2015	01109111	$15.00
ARDUINO USB ELECTROCARDIOGRAPH	OCT 2015	07108151	$7.50
FINGERPRINT SCANNER – SET OF TWO PCBS	NOV 2015	03109151/2	$15.00
LOUDSPEAKER PROTECTOR	NOV 2015	01110151	$10.00
LED CLOCK	DEC 2015	19110151	$15.00
SPEECH TIMER	DEC 2015	19111151	$15.00
TURNTABLE STROBE	DEC 2015	04101161	$5.00
CALIBRATED TURNTABLE STROBOSCOPE ETCHED DISC	DEC 2015	04101162	$10.00
VALVE STEREO PREAMPLIFIER – PCB	JAN 2016	01101161	$15.00
VALVE STEREO PREAMPLIFIER – CASE PARTS	JAN 2016	01101162	$20.00
QUICKBRAKE BRAKE LIGHT SPEEDUP	JAN 2016	05102161	$15.00
SOLAR MPPT CHARGER & LIGHTING CONTROLLER	FEB/MAR 2016	10105161	$15.00
MICROMITE LCD BACKPACK, 2.4-INCH VERSION	FEB/MAR 2016	07102121	$7.50
MICROMITE LCD BACKPACK, 2.8-INCH VERSION	FEB/MAR 2016	07102122	$7.50
BATTERY CELL BALANCER	MAR 2016	11111151	$6.00
DIETA THROTTLE TIMER	MAR 2016	05102161	$15.00
MICROWAVE LEAKAGE DETECTOR	APR 2016	04103161	$5.00
FRIDGE/FREEZER ALARM	APR 2016	03104161	$5.00
ARDUINO MULTIFUNCTION MEASUREMENT	APR 2016	04116011/2	$15.00
PRECISION 50/60Hz TURNTABLE DRIVER	MAY 2016	04104161	$15.00
RASPBERRY PI TEMP SENSOR EXPANSION	MAY 2016	24104161	$5.00
1000B STEREO AUDIO LEVEL/VU METER	JUN 2016	01105161	$15.00
HOTEL SAFE ALARM	JUN 2016	03106161	$5.00
UNIVERSAL TEMPERATURE ALARM	JULY 2016	03105161	$5.00
BROWNOUT PROTECTOR MK2	JULY 2016	10107161	$10.00
8-DIGIT FREQUENCY METER	AUG 2016	04105161	$10.00
APPLIANCE ENERGY METER	AUG 2016	04116081	$15.00
MICROMITE PLUS EXPLORE 64	AUG 2016	07108161	$7.50
CYCLIC PUMP/MAINS TIMER	SEPT 2016	10108161/2	$10.00/pair
MICROMITE PLUS EXPLORE 100 (4 layer)	SEPT 2016	07109161	$20.00
AUTOMOTIVE FAULT DETECTOR	SEPT 2016	05109161	$10.00
MOSQUITO LURE	OCT 2016	25110161	$5.00
MICROPOWER LED FLASHER	OCT 2016	16109161	$5.00
MINI MICROPOWER LED FLASHER	OCT 2016	16109162	$2.50
50A BATTERY CHARGER CONTROLLER	NOV 2016	11111161	$10.00
PASSIVE LINE TO PHONO INPUT CONVERTER	NOV 2016	01111161	$5.00
MICROMITE PLUS LCD BACKPACK	NOV 2016	07110161	$7.50
AUTOMOTIVE SENSOR MODIFIER	DEC 2016	05111161	$10.00
TOUCHSCREEN VOLTAGE/CURRENT REFERENCE	DEC 2016	04110161	$12.50
SC200 AMPLIFIER MODULE	JAN 2017	01108161	$10.00
60V 40A DC MOTOR SPEED CON. CONTROL BOARD	JAN 2017	11112161	$10.00
60V 40A DC MOTOR SPEED CON. MOSFET BOARD	JAN 2017	11112162	$12.50
GPS SYNCHRONISED ANALOG CLOCK	FEB 2017	04102171	$10.00
ULTRA LOW VOLTAGE LED FLASHER	FEB 2017	16110161	$2.50
POOL LAP COUNTER	MAR 2017	19102171	$15.00
STATIONMASTER TRAIN CONTROLLER	MAR 2017	09103171/2	$15.00/set
EFUSE	APR 2017	04102171	$7.50
SPRING REVERB	APR 2017	01104171	$12.50
6GHz+ 100HZ PRESCALER	MAY 2017	04112162	$7.50
MICROBRIDGE	MAY 2017	24104171	$2.50
MICROMITE LCD BACKPACK V2	MAY 2017	07104171	$7.50
10-OCTAVE STEREO GRAPHIC EQUALISER PCB	JUN 2017	01105171	$12.50
10-OCTAVE STEREO GRAPHIC EQUALISER FRONT PANEL	JUN 2017	01105172	$15.00
10-OCTAVE STEREO GRAPHIC EQUALISER CASE PIECES	JUN 2017	SC4281	$5.00
RAPIDBRAKE	JUL 2017	05105171	$10.00
DELUXE EFUSE	AUG 2017	18106171	$15.00
DELUXE EFUSE UB1 LID	AUG 2017	SC4316	$5.00
MAINS SUPPLY FOR BATTERY VALVES (INC. PANELS)	AUG 2017	18108171-4	$25.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER	SEPT 2017	01108171	$20.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER PANELS	SEPT 2017	01108172/3	$20.00/pair
3-WAY ADJUSTABLE ACTIVE CROSSOVER CASE PIECES	SEPT 2017	SC4403	$10.00
6GHz+ TOUCHSCREEN FREQUENCY COUNTER	OCT 2017	04110171	$10.00
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Capacitor Discharge Ignition works on bench but fails in vehicle

A long time ago I built the programmable CDI unit published in the September 1997 issue of SILICON CHIP ("A high-energy capacitor discharge ignition system"; **siliconchip.com.au/Article/4837**).

It was working fine as long as it was tested on the bench. But in the car, the Mosfet driver on the ignition discharge side (IR2155) broke down after a mile.

I put a new one in and tested it on the bench for 48 hours with no problems. Back in the car, one mile and then kaput. Ugh.

The only difference between testing and running in the car was that during testing, I was spinning a distributor with a drill, using the same coil but only one spark plug directly from the high tension side of the coil.

Now I want to use it for an old 2-stroke engine. Please give me some tips on how to tackle this. (L. A., Stavsjö, Sweden)

- The IR2155 drivers are prone to failure due to static electricity discharge and have been discontinued by the manufacturer. The L6571AD is a far more robust IC and should be used instead of the IR2155.

An updated version of the CDI which uses the L6571 is in the December 2014 and January 2015 issues (**siliconchip.com.au/Series/279**).

cables which are clearly made to a better standard since they are unlikely to cause signal connection problems. But will the better cables sound better than the cheap stuff? Probably not.

Optical triggering not working on motorbike

I have just built two High-energy Ignition systems (November-December 2012; **siliconchip.com.au/Series/18**), to be driven by a Piranha trigger assembly on a Suzuki 4-cylinder motorcycle. The units work fine in test mode but when attached to the trigger, do not operate.

All appears to be OK but when I checked the voltage coming from the trigger wire as I rotate the crank, the voltage varies from 3.5-4V when not triggered to 5V when triggered.

I would have thought the trigger voltage should have dropped very close to zero when the diode was conducting but this is not the case.

The difference in on and off voltages does not seem to be enough to operate the ignition units. Has something on the earth side of the power to the trigger system been missed?

I cannot find a reason in the bike itself for this voltage to exist so I am wondering if there should be a lower value resistor in place of the 120Ω current limiting resistor on the circuit board.

The trigger assembly has been modified from original so that each optical trigger works independently where previously the two triggers were wired together, so now each box is a completely separate system. I hope you can shed some light on my problem.

- It may be that the infrared LED in the Piranha trigger is not getting sufficient current. Or maybe the ground connection to the Piranha trigger has a high resistance.

You may need to bench test the Piranha trigger itself first and then connect it to the ignition. If it works during bench testing, then it should work in the vehicle, providing the wiring is the same.

Help with identifying a transistor

I have been asked to repair an ultrasonic cleaner. Initial checks indicated a blown fuse which I changed but of course, it again blew immediately. Further investigation revealed two shorted transistors but I have had no luck in identifying them.

They are both stamped with G29AC J13009-2 and are in TO-220 packages. The circuit appears to run directly from the mains input. I hope you can help because, as usual, I don't have a circuit diagram. (G. C., Moss Vale, NSW)

- We suspect they are FJP13009H-2TU high-voltage, fast-switching NPN transistors. The data sheet indicates the device marking code is J13009-2.

Trickle charging NiCad cell in 2007 Level Meter

I have been using the PIC-based Water Tank Level Meter, described in the November & December 2007 and January 2008 issues, for many years (**siliconchip.com.au/Series/46**).

However, I got tired of replacing the alkaline cell powering it. So I decided to switch to a NiCad cell with a mains power supply to keep it charged. This is where all my problems started.

I fitted the NiCad cell connected a mains DC supply in place of the solar cell shown in Fig.8 on page 37 of the November 2007 issue but the unit no longer works.

If I supply 3V it draws 1A and if I supply 5V it draws 2A which seems too high. What size power supply can I use?

- You need to replace diode D2 with a 1kΩ resistor to limit the current into the rechargeable cell. Without this diode, the supply polarity is critical, so make sure the positive output of the plugpack goes to the + input.

With the limiting resistor, 3V or 5V DC is fine although you could go as high as 12V for more charge current (but you may need a higher wattage series resistor).

List of amplifier projects wanted

Do you have a listing of all amplifier projects from *EA*, *ETI* and SILICON CHIP? (R. G., Bellbowrie, Qld)

- We don't have a listing of SILICON CHIP amplifier projects but it is pretty easy to make one. Just go to our website, click on Articles, then Contents Search, tick the Project box for article type and then type in "amplifier" in the Name field. You will get a list of 136 project articles.

If you want to look at amplifier projects for *EA*, click on Indexes, and then "EA projects from 1968-2000". The first part of the listing is devoted to audio projects, including amplifiers.

Searching *ETI* projects is a bit more troublesome. Again, click on Indexes, then "ETI Index, 1971-1990". This gives the total project list. You could grab the text and put it into a text file and then do a search for amplifier projects. SC

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Coming up in Silicon Chip

El Cheapo Modules – RF attenuators

Jim Rowe describes a programmable, 63-step, 4GHz RF digital step attenuator module with a range of applications.

Gut Gas Sensors

This innovative technology from an Australian university allows doctors to monitor gas levels in the digestive system of patients in real-time. Patients could even potentially go home and come back later as data is logged to a mobile phone via Bluetooth. The logged data can then help diagnose digestive ailments.

Introduction to programming the Cyprus CY8CKIT

This low-cost module incorporates a 32-bit microcontroller and a set of reprogrammable analog circuitry which can be used for a wide range of tasks. We show you how to use the free Integrated Development Environment.

Magic eye display for audio systems

Retro is cool and you can't get much more retro than a 6E1P magic eye valve (electron-ray indicator). It glows green with a dancing pattern that varies with the audio signal applied. Use it as an audio level indicator or just for a fun display to spice up your sound system.

USB Port Protector

If you're developing an Arduino (or similar) project using a PC or laptop and powering it from a USB port, it is possible to accidentally damage your computer. We learned this the hard way. Our low-cost Port Protector greatly reduces the risk by preventing voltages outside the acceptable range from reaching your USB port.

Note: these features are planned or are in preparation and should appear within the next few issues of Silicon Chip.

The May 2018 issue is due on sale in newsagents by Thursday, April 26th. Expect postal delivery of subscription copies in Australia between April 26th and May 10th.

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Notes & Errata

Full Wave 10A Motor Speed Controller, March 2018: The mains Active wiring to the fuse holder shown in Fig.2 should show the incoming mains wire (brown) connecting to the tip of the fuse holder rather than the side ring terminal. The wire through the current transformer should then connect to the side ring terminal of the fuse holder. Also, the paragraph before the "Current Feedback" cross-heading on page 39 refers to pin 2 connecting to the 4.7nF capacitor. It should say pin 5. These errors have been fixed in the online edition.

Budget Senator Loudspeakers, May-June 2016: in the May issue, on page 39: the dimensions given in Figs.4 & 5 are wrong. The correct dimensions are given on page 77 of the June 2016 issue.

Making Power From Rubbish, February 2018: there is an error in the fourth paragraph. The generator produces 52MW, not 52MWh per year.

Circuit Ideas Wanted

Got an interesting original circuit that you have cleverly devised? We will pay good money to feature it in Circuit Notebook. We can pay you by electronic funds transfer, cheque or direct to your PayPal account. Or you can use the funds to purchase anything from the Silicon Chip on-line shop, including PCBs and components, back issues, subscriptions or whatever. Email your circuit and descriptive text to editor@siliconchip.com.au

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